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Decision Analysis in the U.S. Army's Capabilities Needs Analysis

Applications of Decision Analysis Methods to Capabilities Resource Allocation and Capabilities Developments Decisions

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14. ABSTRACT The application of multi-attribute decision analysis in the Army's Capabilities Needs Analysis (CNA) is described. The CNA's two primary purposes require trade-offs and prioritization of more than 1700 program capabilities and 800 capability gap alternatives to provide Capabilities Based Assessment (CBA) recommendations across more than 20 proponents to inform Army planning and programming processes for Program Objective Memorandum (POM) development. The paper expounds upon: the objective hierarchy and value model hierarchy used to analyze multiple conflicting objectives; the development of an additive value model to recommend highest valued alternatives including selection of measures and development of value functions and their scales; the use of a modified Delphi method to refine the analysis results; and the implementation of an open architecture web-based tool to collect and analyze data and socialize results. To date, results of the value model implementation and prioritizations achieved acceptance across decision makers and stakeholders. Detailed sensitivity analysis and analysis of implementation of the mathematic model indicate additional refinement is required to improve preference precision and wide acceptance in the community of practice.					
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Executive Summary

This paper describes the peer reviewed use of multi-attribute decision analysis in the Army's Capabilities Needs Analysis (CNA). The CNA's purpose is to enable prioritization of Army Capabilities Development and Resourcing to meet Joint Warfighting needs through a capabilities-based analysis of Army Warfighting Challenges across Army Capabilities Development Imperatives (i.e., DOTMLPF-P) given Strategic Guidance and results from other key capabilities development work. Director, ARCIC's intent for CNA completion was to provide: prioritized DOTMLPF-P fielded and programmed solutions alternatives across Army Warfighting Challenges to sustain in the Program Objective Memorandum development that enable Army resourcing decision making; prioritized capability gap alternatives across Army Warfighting Challenges recognized by all stakeholders that help focus capabilities development activities; and prioritized recommended Ideas for Non-material and materiel (INMA/IMA) solution alternatives across the most critical gaps across Army Warfighting Challenges to drive future Capabilities Development. The prioritizations of the three sets of alternatives attempt to answer the central objectives elicited from senior leadership: What are the most valued fielded and programmed solutions (DOTMLPF-P program/solution alternatives) in which to sustain investment in order to meet the Army's Warfighting Objectives over the near and mid-term; what capability shortfalls or gaps (gap alternatives) exist where operational risk is unacceptable; and what opportunities does the Army have and in what INMA/IMA solutions should the Army invest, over time, in order to avoid high risk capability gaps in ensure its ability to meet its Joint Warfighting Requirements and field the Army of 2025? The latter question and value model in the triplet of objectives is the focus of many of the Army Force 2025 efforts, especially recommendations on focusing Science and Technology efforts to help solve or mitigate capability gaps. These objectives focused development of the CNA's three prioritization value models. Each of these models consists of four or five hierarchical levels decomposed below the objective that enables operationally relevant, contextual understanding of the

value of each of the three sets of alternatives. These levels include: 6 Support to Strategic Analysis compliance scenarios; more than 90 operating force formations at tactical, operational and strategic echelons; the Army's 20 Warfighting Challenges and the formation's set of Required Capabilities with more than 800 of their associated task, conditions and standard sets /mission essential tasks; and the more than 1700 DOTMLPF-P solution alternatives that provided a degree of ability to achieve the tasks, or the more than 800 capability gap alternatives where the solution sets do not fully achieve the tasks resulting in unacceptable degree of operational risk, and the set of recommended ideas for non-material solution or ideas for materiel solution alternatives to the critical capability gap. The implementation of these value models produced initial prioritized of DOTMLPF-P fielded and programmed solutions, capability gaps and recommended gap solution approaches. Once analyst made initial assessments a refinement process using a modified Delphi method enabled final recommendations that accounted for experience and expertise not fully measured in the value model during the initial assessment. This resulted in a consensus with the final prioritizations across all stakeholders. Analysis, especially sensitivity analysis of the attributes used, showed that generally the attributes and associated constructed scales enabled preference selection among the alternatives. However, preference was seen to be sensitive to moderate change in attribute weighted values in required capability/task attributes level of the value model but were viewed to have little adverse effect on overall result. This provided confidence that the value models provided the preferences for the solution/program alternatives that are most valued and are recommended for sustained investment, gap alternatives with the most unacceptable risk so they can be solved soonest, and investment is focused toward INMA/IMA solution alternatives across those critical capability gaps. The prevalent use of constructed scales relying upon qualitative judgment required a significant manpower and time resource commitment suggesting the need to investigate of the use of more precise performance metrics for attributes representing elements in the value model. This could remove some of the resources required to determine the alternatives' relative

values but the up-front cost to obtain the data necessary to populate the value model is likely to be significant. Refinements of attribute criterion measures are also recommended to improve confidence in the preferences provided. Future improvement of the CNA value models is planned to address each of these refinement recommendations.

Introduction

This paper describes the use of multi-attribute decision analysis in the Army's Capabilities Needs Analysis (CNA). The CNA's two primary purposes require trade-offs and prioritization of many alternative capabilities in order to provide requirements development recommendations across Army functions and formations, and to inform Army resourcing and developments processes and decisions in the Army's Program Objective Memorandum (POM). The CNA uses the methodology for a Capabilities Based Assessment (CBA) as the basis for its method to prioritize among the alternatives. This paper expounds upon that method including: the objective hierarchy and value model hierarchies used to analyze multiple conflicting sub-objectives; the development of an additive value models to recommend highest valued alternatives including selection of measures and development of value functions and their scales; the use of a modified Delphi method to refine the analysis results; and the implementation of an open architecture web-based tool to collect and analyze data and socialize results. Finally, the effectiveness achieved during implementation is presented and areas for improvement are discussed.

The CNA's purpose is to enable prioritization of Army Capabilities Development and Resourcing to meet Joint Warfighting needs through a capabilities-based assessment (CBA) across DOTMLPF-P given strategic guidance and results from other key capabilities development work. Figure 1 graphically depicts the CNA purpose. Key elements of the purpose that needed to be considered during the analysis include: Identifying and assessing '*what the Army must perform?*' in a given scenario; assessing a solution's ability to satisfy what the Army must do. ('*What is programmed, thus should be sustained?*'); Identifying and assessing any resultant capability gaps for areas not satisfied ('*What the Army Cannot do?*'); Identifying and assessing non-materiel and materiel solutions (and interim solutions) to solve or mitigate the critical capability gaps. ('*Where the Army Should Focus Future Investment?*').

FIGURE 1. CNA Purpose

The CNA derives its authority to achieve this purpose from the Army Title 10 role to man, equip and train the land forces to conduct war. Additionally, TRADOC and ARCICs mission is key to making recommendations on the Army's Title 10 role as laid out in Army General Order #4 (GO #4), Army Regulation 71-9 (AR 71-9), Training and Doctrine Command Regulation 71-20 (TR 71-20) and further defined in Chairman of the Joint Chiefs of Staff Instruction 3170.01I (CJCSI 3170.01I). The Director, ARCIC's intent for CNA completion was to provide a prioritized DOTMLPF fielded and programmed solutions to sustain in the POM, and prioritized capability gaps and prioritized recommended solution strategies for the most critical gaps to inform future Capabilities Development and inform Army resourcing. The goal for the CNA was to assess both formations and functions during the analysis in a manner that enables the prioritization under the methodological construct of a Capabilities Based Assessment (CBA).

The scope of the analysis was established based upon the intent and the constraints set by ARCIC leadership. The analysis covers nearly 30 proponent's responsibility for force development of more than 50 formations types that conduct unified land operations represented in 6 warfighting functional areas and 3 special functional areas, across a widely diverse operating environment established in 6 scenarios over a timeframe from today through 2040. Additionally, limitations on time and manpower resources

resulted in TRADOC Centers of Excellence and Force Modernization proponents focusing the scope of the analysis based upon their senior leader's judgment of critical areas to assess resulting in an analysis that sufficiently addresses their area of responsibility vice comprehensively analyzing their entire areas of responsibility.

Analytically, the CNA purpose and leadership intent can be categorized as a multi-attribute decision problem to answer the set of central questions since the problem posed can be summarized as deciding among various alternatives where those alternatives are valued differently across selected criteria (which are derived from the Capabilities Based Assessment (CBA) methodology). Drawing from the Decision Analysis branch of the science of Operations Research, Edwards and Barron[1] as well as others (Kirkwood, Keeney, Parnell, etc.) suggests value modeling as a widely accepted technique in order to address the kind of trade-offs that are required to determine the ordered preference of alternatives as required in the CNA. However, before pursuing the step-by-step method suggested by Edwards and Barron as modified by others to model the multi-attribute decision problem and produce preferred alternatives and ordered list of those alternative, a complete understanding of the nature and extent of the problem is required.

CNA Constraints, Limitations, Assumptions

Before modeling the decision problem presented by the ARCIC leadership, a detailed understanding of the constraints, limitations and assumptions is required to ensure error avoidance yet achieve a comprehensive treatment of the problem. As previously mentioned and discussed here, the analysis is constrained by the decision maker and further limitations in the organizations ability to conduct the

[1] Edwards, W., Barron, F.H., SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement, 1994, Organizational Behavior and Human Decision Processes, 60, pp. 306-325.

analysis resulted in a reduction in the possible scope of the analysis conducted. Additionally, assumptions were required in areas where data was incomplete/unavailable.

Constraints. There were four constraints on the implementation of the CNA and its value models imposed by leadership (here after referred to as Decision Makers (DM)). First, use the available expertise at Centers of Excellence (CoE) to conduct analysis, finishing the analysis annually. Minimize the extent of manpower and time resources to achieve a "good enough" analysis. Although practical, implementation caused considerable friction among participants due to the vague nature of the constraint. The implication of this to the analysis is that not all centers or proponent have available the most qualified experts to assess the alternatives (solutions, formations, gaps, etc.) against the attributes (achievement, risk, etc.) reducing the quality of the assessment of the alternatives against the attributes. Most experts lacked recent experience in the formations assessed and many had been removed from such experience over several generations of formation design and were not intimately familiar with the most recent doctrinal employment of the formation and fielded or programmed solution sets comprising the formation's equipment. Second, use only the 6 Support to Strategic Analysis Scenarios[2] for Capabilities Development (set from 2018 to 2040). This constrains the operational environments (terrain and enemy) considered during the analysis. Although the scenario set was optimized to cover the range of military operations, most of the detail provided for these scenarios focused primarily on Phase III (Dominate) of the Joint Operations Process. This constraint could cause too narrow a focus for capabilities development for the Army resulting in a 'sub-optimal' set of recommendations. This was especially true for Training and Engagement special functional areas where primary tasks are performed in Joint Operational phases I and II. The scenarios were focused primarily at the tactical level of war with allowance for including strategic and operational level where needed to cover critical Required

[2]Krondak, et. al., TRADOC Scenario Gist Book, TRAC-F-TR-13-016, ATTN: ATRC-FD, TRADOC Analysis Center, 255 Sedgwick Ave., Fort Leavenworth, KS 66027-2345

Capabilities and Tasks. These scenarios provided the conditions and context needed to make value judgments required during the analysis. Third, use only the Army Operating Concept, WFF & Other Functional Concepts (representing how to fight though 2040). These concepts provided the critical required capabilities which the analysis used as the foundation for development of detailed tasks, conditions and standards to establish what formations would do in each of the scenarios. Those concepts included the Army Operating Concept, 6 Warfighting Function (WFF) Concepts, the Training, Learning and Education Concept, the Engagement Concept and the Human Dimension Concept. The Required Capabilities are hierarchical in nature with 20 Army Warfighting Challenges representing the overarching enduring problems to be solved and decomposing into Army Warfighting Functional concepts consisting of more than 188 identified across all the concepts. Tasks were developed using Universal Joint Task List, Army Universal Task List (ATP 1-03), and HQDA Standardized Mission Essential Task Lists as a basis in order to provide sufficient detail to enable assessment of the formation or functional capabilities. These tasks' standards were adjusted, where appropriate, to account of the future operating environment detailed in the Army Concepts. Forth, conduct the analysis at an unclassified level to enable the broadest dissemination of the results and information. Where required to achieve inclusion of critical areas that are classified, venues and tools were provided to enable consideration of classified critical areas and materiel. However, all releasable results are to be Unclassified, For Official Use Only.

Limitations. Four limitations were noteworthy. Two limitations on the breadth and depth of the CNA's analytical rigor were necessary due to the constraints and to avoid misunderstanding what CNA covers or does not cover. First, the analysis assesses the Army formations tasks and fielded and programmed DOTMLPF solutions without consideration of dependencies between internal Army or Joint formations in order to determine capability gaps. This is a critical limitation of the analysis since the interaction possibilities in combat operations are nearly infinite and would be impossible to model effectively. The

dependency or needed dependence between formations was documented in the gap solution assessment. Second, only the primary capability or capability set provided by the DOTMLPF-P fielded or programmed solution is assessed to avoid second and third order effects and a violation of mutual independence. Many solutions provide abilities beyond their intended design that provide unintended but potentially beneficial redundancy. To avoid this, assessors were instructed to strictly use the intended ability of a solution to measure achievement of tasks. A third limitation was related to the baseline for each formation. Each formation was assessed based upon its approved Table of Organization and Equipment for Army 2020. This enabled analysis of the effects of programmed capabilities introduction into the formations and provided consistency for across an ever changing Army force structure. The forth limitation involved assessor capabilities. Assessor learning curve associated with newly developed tools and techniques caused assessors to focus away from providing expert judgment during assessments and more on tool functionality. An attempt to overcome this limitation's effect on the analysis results was made through multiple levels of review of answers provided in formulation of the results.

Assumptions: Five assumptions were required where there were deficiencies in data completeness or where the lack of the assumption would not allow assessors to complete the analysis**.** First, everything the Army must do is performed by a soldier, government service civilian, or contractor in an Army formation/organization (Operating Force or Generating Force). This enables easily assigning tasks to the appropriate formation responsible for the task for the Army. Second, the Army will be constrained in resources, thus decisions will be required about what capabilities are needed and where the resourcing should be focused. This is the fundamental assumption that requires the development of the prioritization models in CNA. If resources were unconstrained, then the Army could have everything it needs and preference decisions are not required. Third, the Army invests resources to achieve the

standard (measure and scale) or condition of a task performed by some formation/organization and those investments are effectively managed to ensure fielding of the required capability. This provides the link between tasks and fielded and programmed solutions that require funding. That funding must provide the level of capability to meet the task to the standard under the condition, nothing more or less, else the funding is wasted. Also, that funding for the programmed solution must ensure that the solution is fielded to the Army in order to realize the provided capability. Forth, the Army (2020) formations assessed are organized, equipped and manned to100% fill of the Table of Organization and Equipment for task performance during assessment within the scenarios. This is essential to avoid nearly infinite possibilities where the Army knowingly decided that equipment shortfalls where acceptable in units at home station and experts experience with the shortfall may introduce bias in the assessment. Recent history with ARFORGEN and its successor process verifies that this assumption is reasonable. Fifth, the combination of all included scenarios enable the assessment of all the tasks Army formations must perform across the six Joint Campaign Phases (0-V)[3] thus ensuring that exhaustive coverage of all possible functions and required capabilities. Where this assumption was invalid, especially where the scenarios provided great detail in one phase of operation and only minimal details in the others, the scenario was expanded with the creation of vignettes within the scenario to permit the assessment across all functions and required capabilities.

[3] Joint Publication 5-0, Joint Operation Planning, Department of Defense, August 11, 2011, para. 10, pg III-41.

Analytic Approach and Methodology

The CNA objective, as shown in Figure 2, was established to meet the ARCIC Director's intent. It was developed considering the context of the Army Operating Concept, Army Warfighting Functional Concepts on how to fight in the future, and 5 Defense Planning scenarios (EPP, SSSP, NEA, ISC-B, and AFR) to enable prioritization of Resourcing and Developments through a capability-based analysis across Warfighting and Special Functions as well as Formations. This objective was decomposed into three issues and 11 Essential Elements of Analysis (EEA) to help understand the extent of the problem set needed to answer the CNA objective. In essence, the CNA must determine preferences in three areas:

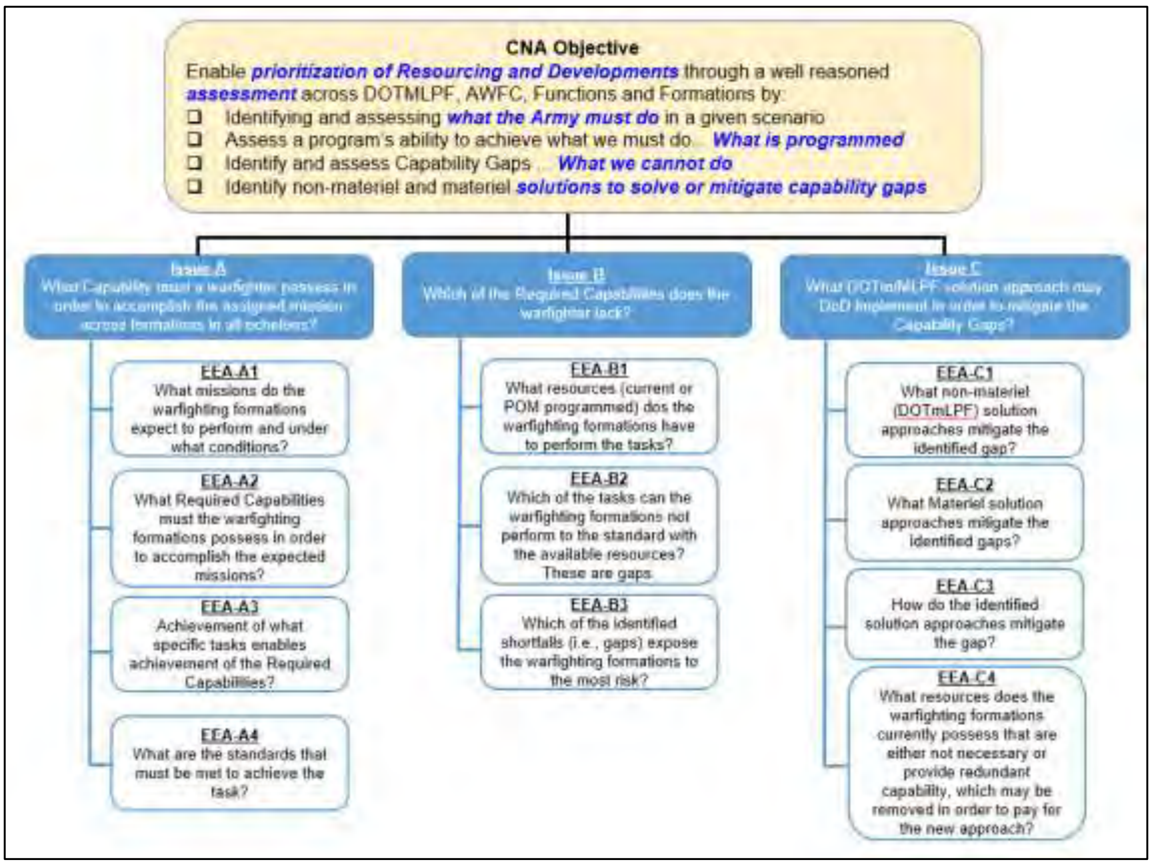

FIGURE 2. CNA Objectives, Issues and Essential Elements of Analysis

Given impending future Department of Defense resourcing constraints, determine the ordered preference of which of the current programmed and fielded solutions to sustain in the force or programmed budget

to ensure it meets its joint warfighting requirements and which can be traded-off with minimal risk to pursue or buy a new capability that mitigates or solves a high risk gap; determine which tasks representing the Army's Warfighting Requirements cannot be achieved, describe the capability gap that results and assess the operational risk of that gap in the scenario set. This provides an ordered preference for which gaps to address soonest; and determine an ordered preference for the solutions that solve or mitigate the gap to enable future investment focus.

These objectives were evaluated in the context of the Keeny's nine desired properties of the set of fundamental objectives.[4] As a result of meeting Keeny's properties, these objectives became the fundamental objectives as part of the analytic approach. An approach (see Figure 3), using a time-phased application of Decision Analysis for multiple conflicting objectives[5] is employed by developing additive value models[6] for each fundamental objective since this technique is suited to provide value preferences between alternatives that can be used to establish priorities and inform decisions. The collection of data and assessment of attributes required of the value model is spread over a period of a year in order to mitigate the effect of constraints on manpower. The approach benefits greatly from an application of web-based assessment tools to collect data from a diverse and geographically dispersed community of practice, assess alternatives and display results in an automated manner. Finally, the Delphi method[7] is used in achieving consensus or at least common understanding among ARCIC and Army Senior leaders and stakeholder about the results of the analysis and preference methods.

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[4] Keeny, R.L., Value-Focused Thinking: A Path to Creative Decisionmaking, Harvard University Press, Cambridge, Massachusetts, 1992, p. 82.
[5] Keeny, R.L., Raiffa, H., Decision With Multiple Objectives, Cambridge University Press, 1993.
[6] Parnell, G.S., Driscoll, P.J., Henderson, D.L., Decision Making in Systems Engineering and Management, 2nd Ed., Wiley and Sons, Inc., 2011.
[7] Linstone, H. A. and Turoff, M. (eds., 1975): The Delphi Method - Techniques and Applications, Reading: Addison-Wesley, 2002.

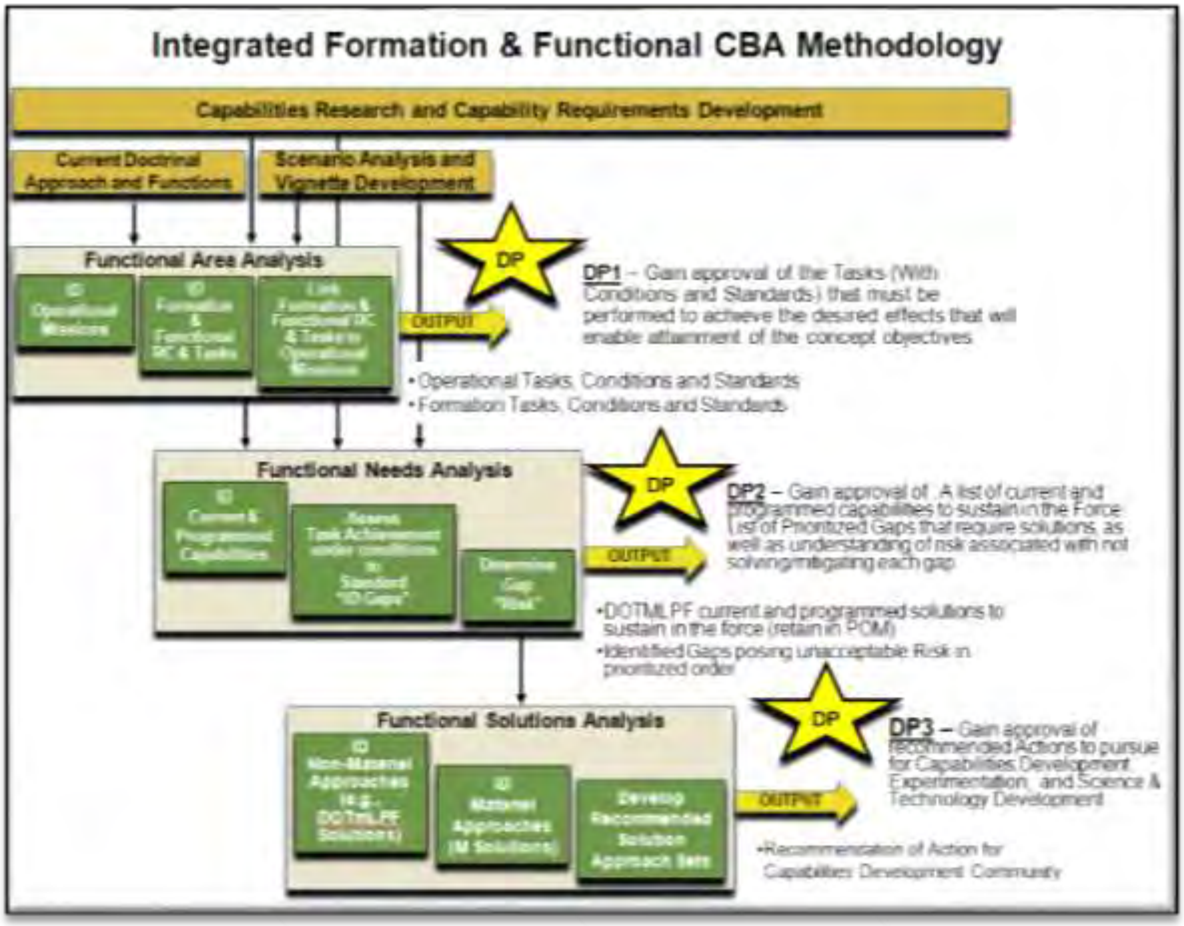


FIGURE 3. CNA Time-Phased Analytical Approach

Value Model Hierarchies

A value model for each of the three fundamental objectives has been developed, with the assistance of the TRADOC Analysis Center (TRAC). These value models account for the logical decomposition of the overarching CNA objective into three fundamental objectives, their associated Essential Elements of Analysis and attributes and metrics that were later assessed during the conduct of the analysis as shown in Figure 4.

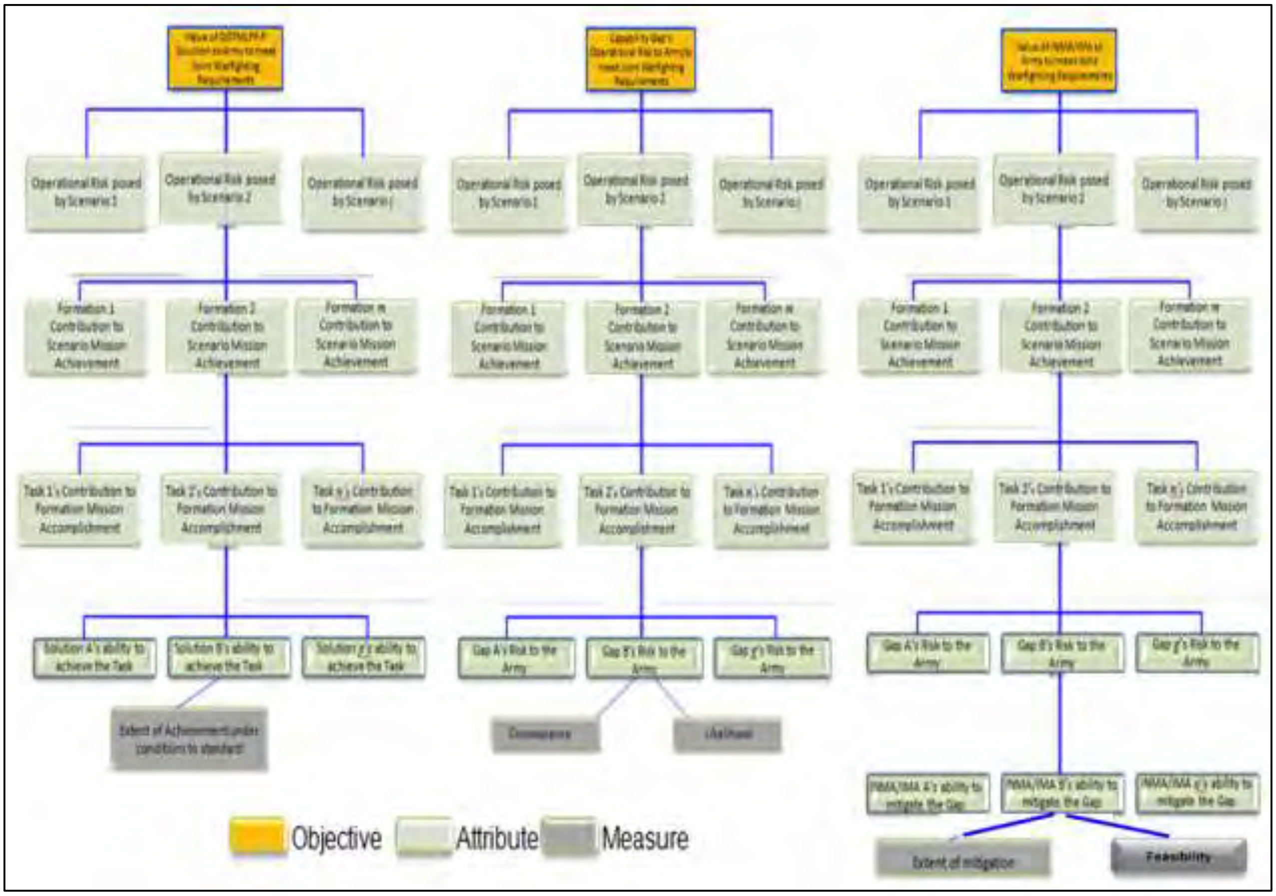


FIGURE 4. CNA Value Model Hierarchies

The additive value model of decision analysis theory, a widely accepted technique, is particularly suited to providing a preference through value determination among the three sets of alternatives (programmed/fielded DOTMLPF-P solutions to sustain in the POM, capability gaps, and DOTmLPF-P Ideas for Non-Material and Ideas for Materiel solutions) across the 4 or 5 attributes derived from the EEAs. These values can then be used to recommend priorities between the alternatives using the associated values.

Additive Value Model

The standard form for an additive n-attribute value model[8] is:

$$V(X) = V(x_1, \cdots x_n) = \sum_{i=1}^{n} w_i v_i(x_i) \qquad (1)$$

Where ***V(X)*** is the multi-attribute values for an alternative X, $\boldsymbol{x_i}$-$\boldsymbol{x_n}$ are the *n* attribute scores for the alternative, $\boldsymbol{w_i}$ is the weight for the $\boldsymbol{i^{th}}$ attribute, and $\boldsymbol{v_i}$ is the single attribute value function for the $\boldsymbol{i^{th}}$ attribute. The weights are swing weights[9], and are positive and normalized so that, $\sum_{i=1}^{n} \boldsymbol{w_i} = \mathbf{1}$**.** The value function measures the returns to scale on the attributes. It is important to understand that there are two conditions that must be met in order to appropriately use the Additive Value Model: preferential independence (specifically mutual preferential independence) and difference independence. Keeney and Raiffa[10] provide a detailed explanation of these conditions. In summary, an additive value model is appropriate when attributes are mutually preferentially independent, that is, the contribution of one attribute to total value of an alternative does not depend upon values in other attributes, and an additive value model is appropriate when differences independence exists, that is, the specification of the differences in values within an attribute do not depend on values in other attributes.

Adaptation of the Additive Value Model for use in priority recommendations in the CNA

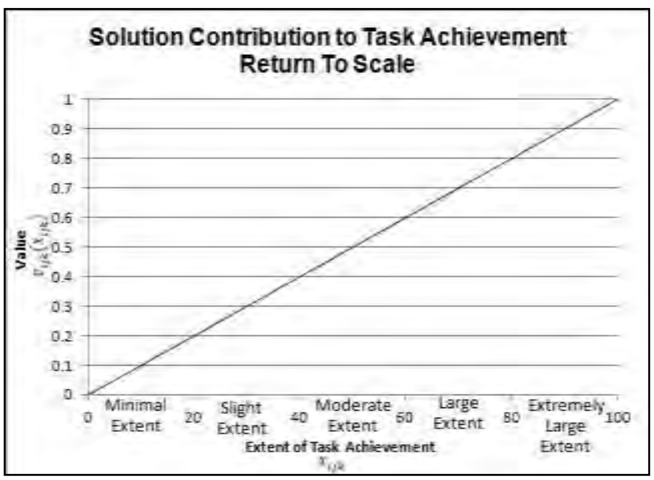
Given the design of the CNA hierarchical value structure of important attributes (e.g., scenarios risk to the Army, formations contribution to achieve scenario objectives, and tasks accomplishment impact on the formation mission accomplishment) associated with the value of the alternatives (e.g., a program's ability to achieve the task, the gap's risk and a solution approach's ability to mitigate a gap and feasibility as shown in Figure 4), the use of the additive value model is appropriate since both mutual

[8] Parnell, G.S., Driscoll, P.J., and Henderson, D.L., Editors**,** Decision Making for Systems Engineering and Management, 2nd Editions, Wiley Series in Systems Engineering, Wiley & Sons Inc. , 2011.
[9] Edwards, W., Barron, F.H., Smarts and Smarter: Improved Simple Methods for Mulitattibute Utility Measurement, 1994, Organizational Behavior and Human Decision Processes, 60, pp. 306-325.
[10] Keeny, R.L., Raiffa, H., Decision With Multiple Objectives, Cambridge University Press, 1993, pp. 104-117.

preferential independence and difference independence exist. The attributes and their returns to scales were design to insure mutual preferential independence. For example, a task attribute's contribution to the total value of a program/gap/solution does not depend upon the contributions to the total value of a program/gap/solution of the other attributes (e.g., formation or scenario). This is also true about each of the attributes. Also, the values associated on the return to scale for a program/gap/solution approach is not related in any way to the preference for a scenario, formation or task where the attribute is being assessed. Similarly, the attributes were chosen and the assessment designed to ensure difference independence. The selection or specification of a value in a programs/gaps/solution approaches does not depend upon the selection or specification of a value in any of the other attributes. For example, the specification of solutions extent of achievement of a task does not depend upon the risk of scenario selection, contribution of formation to scenario end-state accomplishment or contribution of task to formation mission accomplishment. Thus, an adaptation to the multiple attribute additive value model can be made. The application of the value model is normally done by assessing local swing weights for attributes at each level of the value hierarchy: For obtaining the value of a DOTMLPF fielded or programmed solution for example, at the scenario level, weights $\boldsymbol{s_i}$ are assessed for each scenario $\boldsymbol{i}$ then normalized so that $\boldsymbol{\sum_{i=1}^{5} s_i = 1}$; At the formation level, a weight $\boldsymbol{f_{ij}}$ is assessed for each formation $\boldsymbol{j}$ in each scenario **i,** then normalized so that $\boldsymbol{\sum_{j=1}^{m} f_{ij} = 1}$ for all $\boldsymbol{i}$**,** where a formation that is not involved in a scenario gets a value of 0. (e.g., f_{ij}=0); At the task level, a weight $\boldsymbol{t_{ijk}}$ is assessed for each task k in each formation j in each scenario i so that $\sum_{k=1}^{n} t_{ijk} = 1$ for all $\boldsymbol{i}$ scenarios and $\boldsymbol{j}$ formations. Again, if a task is not performed by a formation in a scenario then t=0. Therefore, $w_i = \sum_i \sum_j \sum_k s_i f_{ij} t_{ijk} = 1$, where $\boldsymbol{w_i}$ is the additive model weight and the local weights product is $\boldsymbol{s_i f_{ij} t_{ijk}}$. Additional weights can be added as appropriate for the value model as will be shown later as long as the $\sum_{i=1}^{n} w_i = 1$ condition is met.

DOTMLPF-P Fielded and Programmed Solution (Programs) Alternative Values

For programs to sustain in the POM, the prioritizing value accounts for applicability across tasks, formations, and scenarios, and the degree to which the solution helps achieve those tasks. Since this method is ratio-based, comparing two items in a final priority will show both which one is more preferred and how much more preferred it is in comparison to another program. Thus, for a program P, let it have a performance value $\boldsymbol{x_{ijk}}$ associated to each task $\boldsymbol{k}$, in formation $\boldsymbol{j}$ and scenario $\boldsymbol{i}$, where $\boldsymbol{v_{ijk}(x_{ijk})}$ is a measure of ability to achieve the task under the conditions to the standard on the return to scale of the achievement value function, assumed to linear, as shown in Figure 5.



- **Extremely Large Extent –** the solution, as designed, has the ability to achieve the entire task, under all conditions and meets all standards.
- **Large Extent –** the solution achieves most but not all parts of the TCS.
- **Moderate Extent –** the solution achieves multiple parts to the task, conditions or standards.
- **Slight Extent-** the solution achieves less than 25% of the task under the conditions to the standard. At least the task, a condition and or a standard can be achieved with the solution.
- **Minimal Extent –** the solution does not provide successful achievement of the task under any condition to any standard.

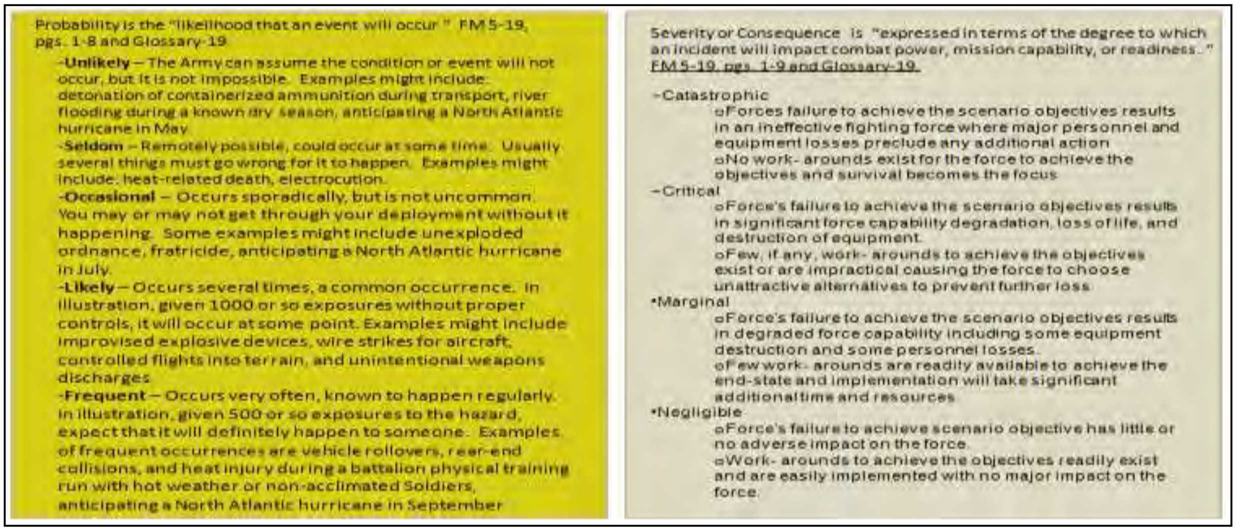
Figure 5. Solution (Program) Achievement of Task Constructed Return to Scale & Criteria

Thus, computation of a program's aggregated value[11] across all tasks, formations and scenarios, given the terms as defined above, can be defined as:

$$V(X) = \sum_{i=1}^{5} \sum_{j=1}^{m} \sum_{k=1}^{n} s_i f_{ij} t_{ijk} [v_{ijk}(x_{ijk})] \qquad (2)$$

[11] Bott, J.M., Gross, A.A., Burk, R.C., Parnell, G.S., CAA Peer Review of ARCICs CNA Process, White Paper, Feb 2014.

Where the normalized scenario weights for each scenario $\boldsymbol{i}$, are given by, $\boldsymbol{s_i} = \frac{l_i c_i}{\sum_{i=0}^{n=5} l_i c_i}$, and the attributes $\boldsymbol{l_i}$, representing the likelihood that the Army would be required to conduct operation similar to those in the scenario, and $\boldsymbol{c_i}$, representing the consequence of Army mission failure in a scenario are obtained using an assumed linear constructed return to scale with well-defined criteria based upon FM 5-19 as shown in Figure 6.



Probability is the "likelihood that an event will occur " FM 5-19, pgs. 1-8 and Glossary-19

-**Unlikely** – The Army can assume the condition or event will not occur, but it is not impossible. Examples might include: detonation of containerized ammunition during transport, river flooding during a known dry season, anticipating a North Atlantic hurricane in May

-**Seldom** – Remotely possible, could occur at some time. Usually several things must go wrong for it to happen. Examples might include: heat-related death, electrocution.

-**Occasional** – Occurs sporadically, but is not uncommon. You may or may not get through your deployment without it happening. Some examples might include unexploded ordnance, fratricide, anticipating a North Atlantic hurricane in July.

-**Likely** – Occurs several times, a common occurrence. In illustration, given 1000 or so exposures without proper controls, it will occur at some point. Examples might include improvised explosive devices, wire strikes for aircraft, controlled flights into terrain, and unintentional weapons discharges

-**Frequent** – Occurs very often, known to happen regularly. In illustration, given 500 or so exposures to the hazard, expect that it will definitely happen to someone. Examples of frequent occurrences are vehicle rollovers, rear-end collisions, and heat injury during a battalion physical training run with hot weather or non-acclimated Soldiers, anticipating a North Atlantic hurricane in September

Severity or Consequence is "expressed in terms of the degree to which an incident will impact combat power, mission capability, or readiness." FM 5-19, pgs. 1-9 and Glossary-19.

–Catastrophic
- Forces failure to achieve the scenario objectives results in an ineffective fighting force where major personnel and equipment losses preclude any additional action
- No work- arounds exist for the force to achieve the objectives and survival becomes the focus

–Critical
- Force's failure to achieve the scenario objectives results in significant force capability degradation, loss of life, and destruction of equipment.
- Few, if any, work- arounds to achieve the objectives exist or are impractical causing the force to choose unattractive alternatives to prevent further loss

•Marginal
- Force's failure to achieve the scenario objectives results in degraded force capability including some equipment destruction and some personnel losses.
- Few work- arounds are readily available to achieve the end-state and implementation will take significant additional time and resources

•Negligible
- Force's failure to achieve scenario objective has little or no adverse impact on the force.
- Work- arounds to achieve the objectives readily exist and are easily implemented with no major impact on the force.

Figure 6. Scenario Operational Risk Constructed Scale Criteria

The normalized Formation weights, $\boldsymbol{f}_{ij}$, are obtained for each formation $\boldsymbol{f}$ in scenario $\boldsymbol{i}$, using an assumed linear constructed return to scale with criteria as shown in Figure 7, so that $\sum_{j=1}^{m} \boldsymbol{f_{ij}} = \mathbf{1}$ within each scenario $\boldsymbol{i}$.

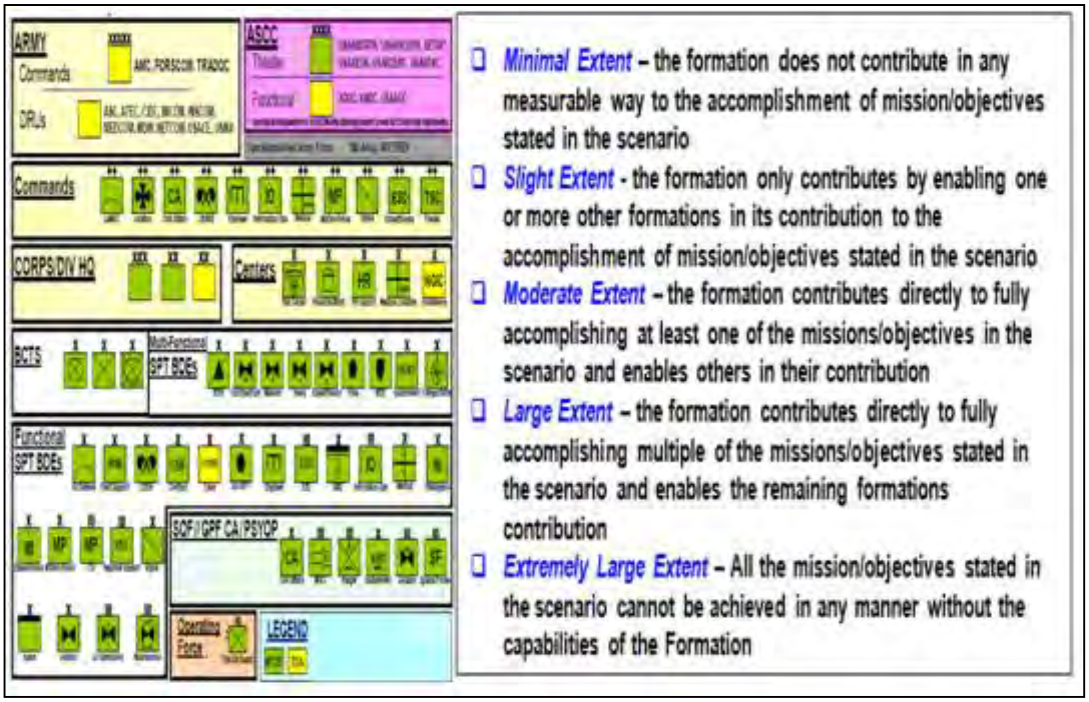


Figure 7. Formations Assessed[12] and Formation Constructed Scale Criteria

The normalized task weights, t_{ijk}, for q tasks are obtained for each formation j and scenario i where, $t_{ijk} = \frac{m_{ijk}\, a_{ijk}}{\sum_{ijk=1}^{q} i_{ijk} a_{ijk}}$, and the impact on formation mission accomplishment is m_{ijk}, and the extent of force mission achievement given successful completion of the task, a_{ijk}, are obtained through assessment of constructed scales as shown in Figure 8, so that all tasks within a formation have weights where, $\sum_{k=1}^{q} t_{ijk} = 1$. Again, if a task is not performed in the formation in the scenario it is assessed a $t_{ijk}=0$.

[12] Army Formation Leader Book, DAMO-FM, Headquarters, Department of the Army, v31, November 21, 2013.

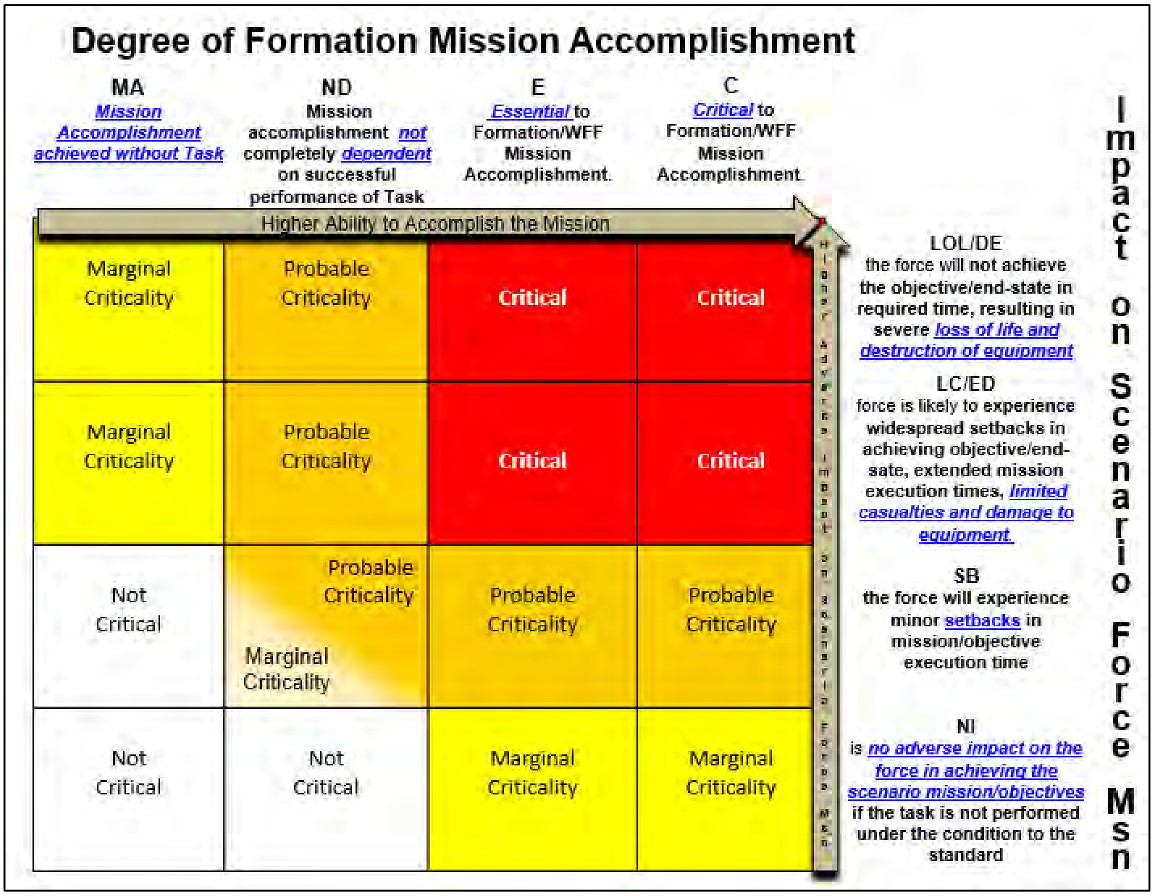


Figure 8. Task Constructed Scale Criteria

Thus, from this construct, a comparison of ***V(X)*** for each program provides a means to prioritize the programs according to the preference value of achieving the Army's tasks across formations and scenarios. Additionally, this construct contributed to understanding and cogent decision making by enabling the categorization of the solutions into Tiers of decreasing value to the Army using the operational logic shown in Figure 9. It is important to note that the breaks between tiers were set by group of quintiles of solution value.

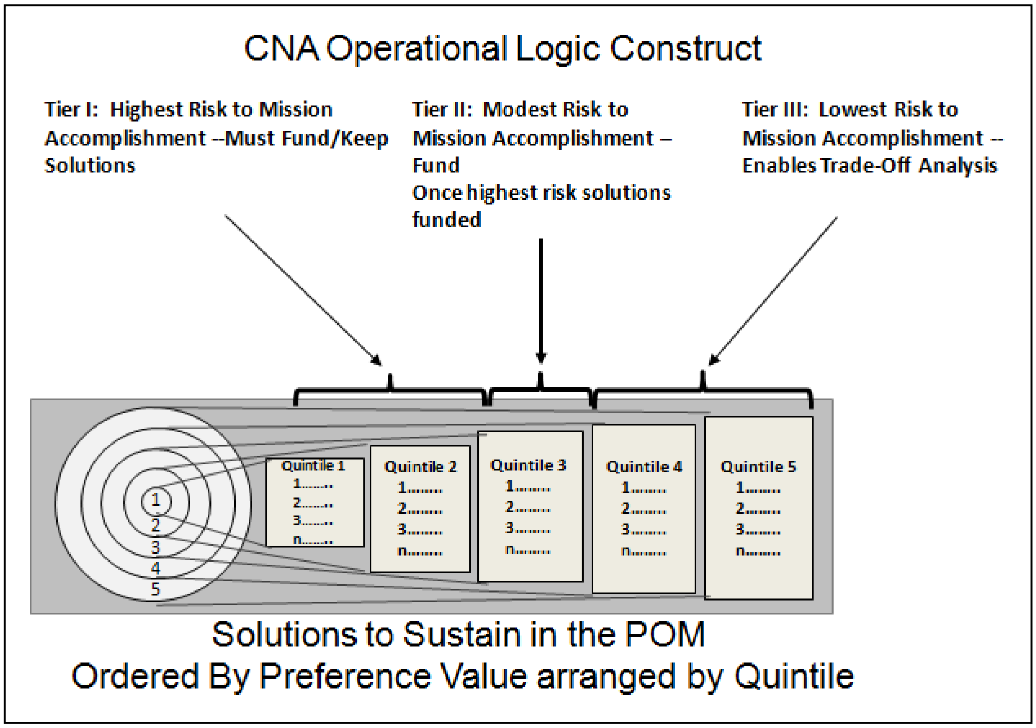
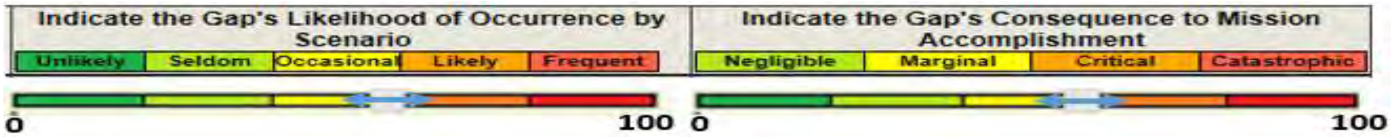


Figure 9. Solution Tiering to Enable Decision Making

Capability Gap Operational Risk Values

For the Capability Gap preference and prioritization to enable solution or mitigation of the highest risk gap first, application of the additive value model in a similar manner as described above was developed. Again, the scenarios, formations and tasks attributes remain the same, e.g., $s_i f_{ij} t_{ijk}$. For a Capability Gap G, let it have a risk value $g_{ijk}(y_{ijk})$ where y_{ijk} is the gaps return on the scales for the gap's consequence and likelihood of occurrence operational risk measure, as shown in Table 1, in scenario ***i*** for formation ***j*** and task ***k*** in a similar manner as solutions.



Criteria	Likelihood (l_{ik}): The frequency the Army will encounter the capability gap in operations represented by the scenario set.		Consequence (c_{ik}): Degree to which the capability will impact Army mission capability, combat power, or readiness in the operations represented by the scenario set.	
Sub-Criteria	Frequently	The capability gap occurs very often, known to happen regularly for conditions in the Operations represented in the scenario(s).	Catastrophic	The existence of the gap results in complete mission failure for the Army in the operation(s) represented in scenario(s). This risk is inclusive of each of the following indicators in the scenario set: loss of ability to accomplish the mission; death or permanent total disability of much of the force; loss of major or mission-critical systems or equipment; major property or facility damage; severe environmental damage; mission-critical security failure; unacceptable collateral damage. The gap cannot be mitigated by any adjustment of tactical procedures, techniques given the available DOTMLPF fielded and programmed solutions.
	Likely	The capability gap occurs for multiple conditions, and is common occurrence in operations represented by the scenario(s).	Critical	The existence of the gap results in severely degraded Army mission capability or readiness in operation(s) represented in the scenario(s). This risk is inclusive of each of the following indicators in the scenario set: permanent partial disability or temporary total disability; extensive major damage to equipment or systems; significant damage to property or the environment; security failure; significant collateral damage. Significant changes in tactical procedures and techniques and adjustment to distribution of existing fielded and programmed DOTMLFP solutions required to mitigate gap to acceptable risk.
	Occasionally	The capability gap occurs sporadically under some of the conditions in the operations represented by the scenario(s), but is not uncommon to Army operations.	Marginal	The existence of the gap causes degraded mission capability or Army readiness. The gap can be mitigated by dedicate effort to change tactics, techniques and redistribute available fielded or programmed DOTMLPF solutions. The risk is inclusive of the following indicator: minor damage to equipment or systems, property, or the environment; lost days due to injury or illness; minor damage to property or the environment.
	Seldom	The occurrence of the gap is remotely possible; it could occur under only very few conditions during the operations represented by the scenario(s).	Negligible	The existence of the gap has little or no adverse impact on mission capability of the Army for the scenario(s) where it occurs. Gap is easily mitigated with tactics, techniques and procedures with the existing DOTMLPF solution set available to meet standards.
	Unlikely	The capability gap is not likely to occur, but it is not impossible to occur in the operations represented by the scenario(s).		

Table 1. Gap Risk Criteria and Sub Criteria and Scales

However, combinations of degrees likelihood of gap occurrence (frequent, likely, occasional, seldom, unlikely) and consequence of the gap on the Army mission accomplishment (catastrophic, critical, marginal, slight) in the scenario are categorized into four levels of relative risk as shown in Figure 10.

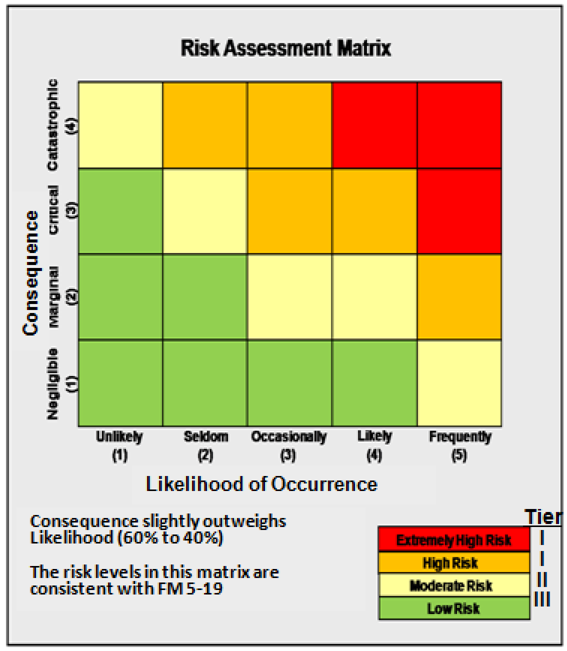
Definitions

Extremely High Risk – The Gap is will occur in all operations (ranging from likely to frequent occurrence) and the Army has lost the ability to accomplish the mission as a result. It is deemed that it is not possible to mitigate the gap, given the fielded and programmed DOTMLPF solution set available, on the spot with tactical procedural changes or addition of other resources (even from outside the operation) during performance of the task in the mission set represented by the scenario(s). This implies that the risk associated with this capability gap will have severe consequences (critical or catastrophic) beyond those associated with this specific operation in the scenario(s).

High Risk – The gap is likely to occur (ranging from seldom to likely) in one or more of the mission sets represented by the scenario(s). The Army's ability to accomplish the mission is severely degraded requiring one or more drastic adjustments in tactical procedures and techniques and commitment of additional resources, given the availability fielded and programmed DOTMLPF solution set, to mitigate the gap. This implies that the risk associated with this capability gap causes consequences for the commander associated with this other elements of the operation in the Scenario.

Moderate Risk – The gap occurs infrequently (ranging from unlikely to seldom) in one or more of the mission sets represented by the scenario(s). The Army can accomplish the mission with the existing fielded and programmed DOTMLPF solution set available but requires adjustment of tactical procedures and techniques and reallocation of existing resources to mitigate the gap. This implies the risk associated with this capability gap causes acceptable consequences (marginal or critical) for the commander regarding other elements of the operation in the scenario.

Low Risk – Expected losses have little or no impact on accomplishing the mission. Injury, damage, or illness are not expected, or may be minor and have no long term impact or effect.



1) Gaps are first binned according to severity (consequence) and probability (likelihood) IAW diagram above (Tier I = EH, H risk, Tier II = M risk, Tier III= L risk)
   - Ensures gaps are ordered according to ***highest risk***
2) Within bins, gaps scored according to:
   - ***Scenario value*** – based on the consequence and likelihood of the scenario where the gap derived from
   - ***Task value*** – degree of impact on the force if the task is not performed

Risk Value – based on COE's assessment of Capability Gap's risk to Organization's mission accomplishment in scenarios.

Tier I – Critical – Must Fully Solve or Mitigate to Ensure Mission Accomplishment

Tier II – Moderate – Develop & implement Solution Strategies as Tier I is resolved

Tier III – Low – Plan mitigation & solve as time & resources allow

Figure 10. Overall Operational Risk Categories

The Overall Risk assessed served as a bin to segregate gaps qualitatively before the gap value model determined preference among gaps within the bins.

Computation of a gap's aggregated risk value across tasks, formations and scenarios can be defined as:

$$G(Y) = \sum_{i=1}^{5} \sum_{j=1}^{m} \sum_{k=1}^{n} s_i f_{ij} t_{ijk} [g_{ijk}(y_{ijk})] \qquad (3)$$

Thus, a comparison of ***G(Y)*** for each gap and its characterized risk in accordance with ATP 5-19 (Extremely High Operational, High Operational Risk, Moderate Operational Risk, and Low Operational Risk) provides a means to prioritize the gaps according to their risk value of not meeting the Army's tasks across formations and scenarios.

Values for Ideas for Non-Materiel and Materiel Approaches (INMA/IMA) Alternatives to Solve Capability Gap to enable Preference

To solve a gap, experts assessed individual INMA/IMA ability. The application of the additive value model was done in a similar manner, as described above, in order to enable investment in the most preferred INMA/IMA for the highest risk gaps. Again, the scenarios $\boldsymbol{i}$, formations $\boldsymbol{j}$ and tasks $\boldsymbol{t}$ attributes remain the same, e.g., $\boldsymbol{s_i f_{ij} t_{ijk}}$. So, in this instance, we consider an additional attribute, gap risk, since we are concerned about solving highest risk gaps soonest. Thus, let the weight associated with $\boldsymbol{r}$ gaps that an INMA/IMA helps solve or mitigate be defined as the normalized value of gap risk, $g_{ijk}(y_{ijk})$. It is simply added to the model and has the value given by $g_{ijk}(y_{ijk}) = \frac{\boldsymbol{l_{ijk}c_{ijk}}}{\sum_{ijk=0}^{r} \boldsymbol{l_{ikj}c_{ijk}}}$. It is the normalized value for a gap's risk associated with the INMA/IMA solving or mitigating gap $\boldsymbol{r}$ across task, $\boldsymbol{k}$, formation, $\boldsymbol{j}$, and scenario, $\boldsymbol{i}$, so that $\sum_{ijk=1}^{r} \boldsymbol{g_{ijk}} = \boldsymbol{1}$. Now for a feasible mitigating solution/idea, $(\boldsymbol{z_{ijkr}})$ associated with gap $\boldsymbol{r}$, let, $\boldsymbol{M_{ijkr}(z_{ijkr})}$ be the value of the product of the extent it provides to mitigate the gap $\boldsymbol{r}$ in task $\boldsymbol{k}$ of formation $\boldsymbol{j}$ in scenario $\boldsymbol{i}$ on a 0-100 scale and a constant, solution/idea feasibility, $\boldsymbol{\lambda}$, as shown in Figure 11. Thus, let λ, be the measure of feasibility of a solution/idea, z, which is a constant value no matter which gap $\boldsymbol{r}$ it is associated with, in task k of formation j and scenario i, so that, $\lambda = \ Tr\ Sp\ Af$.

Extremely Large Extent	Extremely Large Extent - The solution/idea mitigates all (>80%) identified deficiencies in standards or condition of the gap in the scenario and formation and reduces the gap multiple levels to an acceptable level of risk (Low-Moderate).
Large Extent	Large Extent - The solution/idea mitigates the majority (50-80%) of the identified deficiencies in standards or condition of the gap and achieves a reduction in gap risk one or more levels including to an acceptable level of risk (at least Moderate).
Moderate Extent	Moderate Extent - The solution/idea mitigates many (49-25%) of the identified deficiencies in standards or condition of the gap. This level of mitigation may not be sufficient to reduce risk to an acceptable level but reduces risk one or more levels.
Slight Extent	Slight Extent- The solution/idea mitigates a some (24-10%) of the identified deficiencies in standards or condition of the gap. This level of mitigation is not sufficient to reduce gap risk any level.
Minimal Extent	Minimal Extent - The solution/idea mitigates few (<10%) of the indentified deficiencies in standards or condition and does not mitigate the gap risk any level.

Feasibility Attribute				
Attribute Component	Constructed Scale			
	Measure	Low	Moderate	High
Technical Risk Tr	Assigned Value	100	50	10
	For material approaches only, measures the risk that arises from activities related to technology, design, engineering, manufacturing, and the critical technical processes of test, production, and logistics.	acceptable risk	acceptable risk, but with some potential for unforeseen consequences	acceptable risk but with a great degree of unforeseen consequences
Supportability Cost Sp	Assigned Value	100	50	10
	Generally considered only for material approaches, but could include frequency spectrum, munitions, intelligence, IT and National Security System, etc. Supportability measures the impacts of a materiel change on the current means to support such a capability.	comparable support requirements to current system	requires some changes to the current support system	requires significant changes to the current system
Affordability Af	Assigned Value	100	50	10
	Measured relative to rough order of magnitude (or banded) costs associated with similar approaches.	lower cost than current or known similar approaches	comparable to current or known similar approach	higher cost than current or known similar approaches

Figure 11. Solution Approach/Idea Value Scale Criteria

Then, the total of values of a solution/idea, Z, across all gaps it helps mitigate, is defined as S(Z), and is given by:

$$S(Z) = \sum_{i=1}^{5} \sum_{j=1}^{m} \sum_{k=1}^{n} \sum_{r=1}^{o} s_i \, f_{ij} \, t_{ijk} g_{ijk} \, \left[M_{ijkr}(z_{ijkr})\right] \qquad (4)$$

Also, a common factor in all solution approaches/ideas for solving or mitigating a capability gap is the notion of the feasibility of the solution achieving the mitigation/resolution. This factor is a measure of the uncertainty of the solution/idea being embraced by the Army, investment made and fielding achieved. This process often requires multiple years of effective management to bring the solution to fruition within the Army, therefore it cannot be a foregone conclusion that the solution will exist in the timeframe expected or required. Feasibility, consistent with Joint Capabilities Integration and Development System[13], is a combination of three factors, technical risk (*Tr*) associated with the solution/idea, supportability costs differences (*Sp*) from similar approaches being used currently, and an estimate of the affordability (*Af*) based upon similar approaches costs and takes the form

Thus, a comparison of S(Z) across gaps provides a means to prioritize the gap solutions/ideas according to their mitigation value for solving gaps in tasks across formations and scenarios accounting for uncertainty in the pursuit of that solution/idea. It is important to note that non-materiel solutions/ideas do not have a technical risk therefore those solutions/ideas were given maximum value on the scale. This insures consistency with the JCIDS guidance to consider non-materiel approaches prior to materiel approaches first since they are generally less cost.

Given the formulation of the CNA value models above, ARCIC implemented a set of web-based tools, and extensive training of a more than 60 subject matter expert assessors representing Decision Makers across the command on the tools and the metrics to ensure accuracy of the data collected associated with

[13] TRADOC Capabilities-Based Assessment (CBA) Guide, v3.1, U.S. Army Training and Doctrine Command, ATFC-OP, FT Eustis, VA 23604 10 May 2010 p8,

the metrics using their constructed scales. It is important to note that no discussion of the science associated with the use of scales and implementation of scales in a survey (web-based) of the experts is provided here as it is complex and would distract from the primary purpose of this paper. The next section discusses the results and finding of the implementation of the value model approach as outlined here. Included is discussion of the level of confidence the Army Leadership/decision makers can have in the CNA recommendations.

Implementation Results Discussion

In order for the value models to be used in providing recommended preferences from the community of practice to decision makers, the community, as well as, the decision makers must have confidence that the resulting recommendations are the correct representation of the community's preferences and the value measures represent the attribute being measured as precisely as possible. Thus, the results must reflect the values of the decision makers and the community of practitioners in the art and science of Capabilities Development and be mathematically correct in their implementation. This is a particularly challenging requirement considering the scope of the CNA, where there are multiple levels of practitioners and decision makers. Discussion on getting it right could consume many pages in this paper, so only a summary of the effort to achieve "right" is provided here. Drawing on the experience of the TRADOC Analysis Center (TRAC), and the Center for Army Analysis (CAA) and the wisdom of senior leaders and analysts an understanding of what right looks like was achieved. Essentially, the goal for the CNA analysis was to achieve a "good enough'' standard which included the extent of functions across the Army to be assessed, the number of detailed/integrated versus segmented formation assessments, the extent of the representation of the current and programmed capabilities, and the number and breadth of situations (scenarios) to represent the realm of possible operational environments and threats. Early in the initiation of the CNA, these were presented to the community and the decision makers for resolution. The decision makers made adjustments given the resources available, but in the

end the community wholeheartedly supported the resulting preferences as representing the Army's ability to meet its Joint Warfighting requirements, even though "holes" were identified. Thus, the level of "good enough" acceptability of the results was achieved up to and including the 4-star level. From a scientific perspective, however, spurred on by a peer review conducted by CAA, detailed post-hoc analysis showed that adjustments to some processes, attributes, and metrics are warranted to achieve greater precision in the preference recommendations and acceptability. Accordingly, the post-hoc analysis included: an analysis to examine value function relevance including analysis of significant differences in means derived from sampling of the capabilities development population where sampling of experts was used; sensitivity analysis of changes in attribute weightings effect on preferences; and correlation sensitivities between ranks of weighted attributes and alternative ranks.

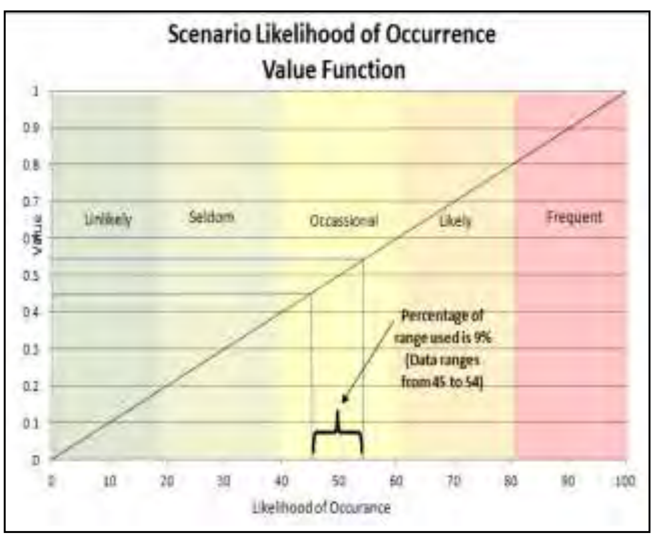
Measure Value Function Relevance and Testing for Measure Sample Mean Differences

Accurate assessment of measures for an attribute in the value model is essential to determination of preference among alternatives, especially when the attribute is to be used as a key weight in the value model. In a perfect model of the type needed here (where few if any natural scales exist thus quantitative analysis is not wholly feasible), it is desirable to have a qualitative value function with a constructed scale with non-overlapping scale increments with well-defined criteria associated with each scale increment in order to use the entire extent of the scale increment vice grouping preferences in only one or two of the scale increments.[14] Additionally, to have confidence in the selected preferences among alternative, it is important that there is consensus in the value samples and significant differences in the means exist where sampling was used to determine values on the scale that will be used for the weights in the value model. To ensure preference determination is not

[14] Ewing, L., Dell, R.F., MacCalman, M., Whitney, L., Capability Portfolio Analysis Tool (CPAT) Verification and Validation Report. Defense Technical Information Center, NPS-OR-13-001, Naval Postgraduate School, Monterey California, January 2013.

artificially constrained by the scale of the metric selected to measure an attribute, analysis alternatives should be measured over a large part of the range of the scale. (e.g., distributed across the scale vice focused in only one or two areas of the scale). Generally, the relevance of the measure to make preference selections would be questionable should assessors: value all alternative in only a small section of the possible scale; there was a lack of consensus for sampled values; or there was no differences in the means for the sampled values.

Scenario Risk to Mission Accomplishment Attribute. The scenario risk attribute was one of two attributes where a panel of experts from across the Army was surveyed to determine the preference for the alternatives. For the scenario attribute, examination of Figure 12 shows the plotted range of scenario sample means on the constructed scales used as a swing weight in the value model for 'Likelihood of Occurrence of Army Operations' measure and the scenario means in the value model for 'Consequence to the force mission accomplishment' measure in the scenario risk attribute. For likelihood of occurrence measure, the means of assessor's characterization of all five scenarios were in the occasional level of occurrence using 9% of the total possible scale.



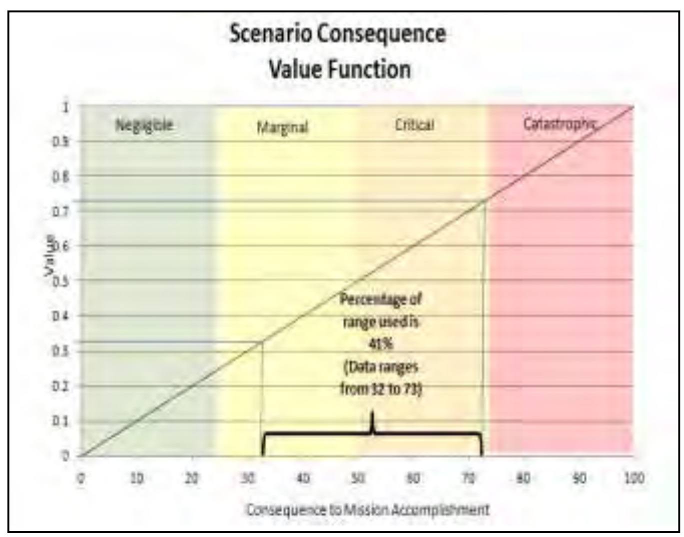


FIGURE 12. Scenario Value Function Relevance

The result was predictable in that these five scenarios were prescribed by the Department of Defense as likely to occur. However, the result of small variation in the means is more attributed to of a lack of consensus among the assessors as to exactly how likely the Army would be to face operations similar to those in the provided scenarios. Examination of Figure 13 shows the lack of consensus result even though two iterations of Delphi method were used to try to achieve consensus. A one-way ANOVA with a 95% confidence level for the likelihood measure showed no significant difference among the means ($p>.05$). Thus, the likelihood measure for the scenario attribute should be considered ineffective in assisting in determining preference of one scenario as more likely than another. Accordingly, the likelihood measure was only used to establish a degree of likelihood of each scenario as one component in the Scenario Operational Risk measure and no statement of the likelihood of occurrence of the Army performing operations similar to the operations presented in the scenarios is made as part of the overall result.

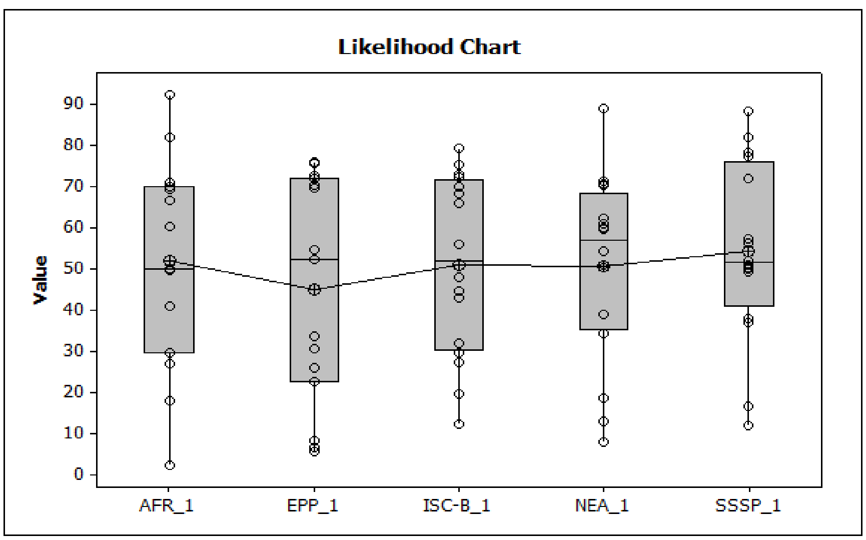


Figure 13. Likelihood of Occurrence Value Function Data

For the consequence measure, the means were in two of four possible consequence categories, Critical and Marginal consequence spanning 41% of the total possible scale. This indicates that the consequence scale was marginally relevant in distinguishing among scenario consequence preferences.

Examination of Figure 14 reveals that there was a good level of consensus among assessors about the degree of consequence to the Army's mission accomplishment should operations be required in a scenario. A one-way ANOVA with 95% confidence level for the mean consequence values revealed significant differences among the means ($p<.05$). As can be seen by inspection of Figure 12, moderate consensus in the sample exists and a Tukey Method test revealed groupings of similar consequence means between EPP, NEA and ISC-B; between ISC –B and SSSP; and Between SSSP and AFR.

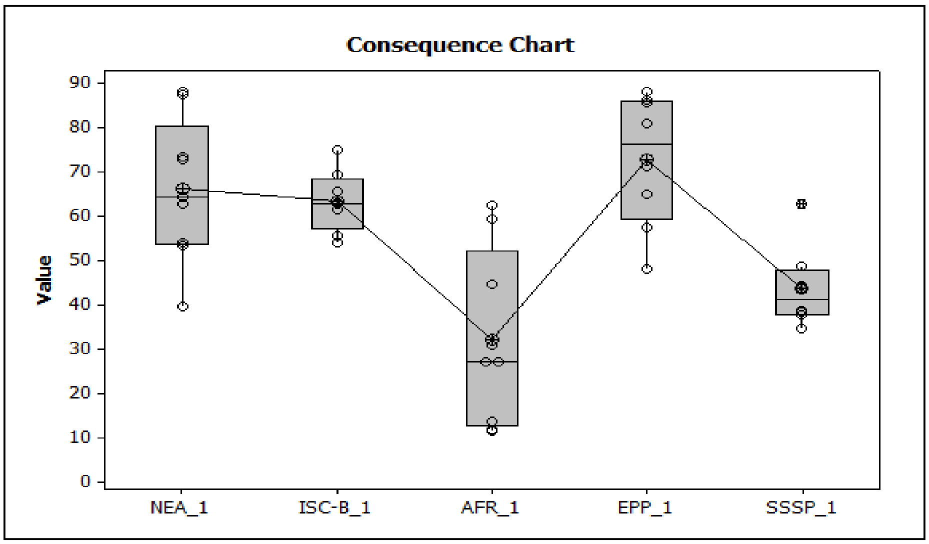


Figure 14. Consequence Value Function Data

Thus, the consequence measure serves adequately to distinguish preference among the scenarios. The result for the scenario risk to the Army attribute (product of likelihood and consequence) was dominated by the consequence preferences thus the derived scenario weights also had significant differences sufficient to enable distinguishing between the risks of scenarios.

Formation Contribution Attribute

The formation attribute was the second of two attribute measures using a sampling of the Army's Formation Design experts. Inspection of Figure 15 reveals a wide distribution of formation means for the 'Extent of Contribution to Scenario Mission Accomplishment' measure from the constructed scales used as a swing weight in the value model. The result indicates that the 80% of the scale was used in each scenario to differentiate between formations' contribution to mission accomplishment in that scenario. However, no formation was assessed in the extremely large extent criteria in any scenario.

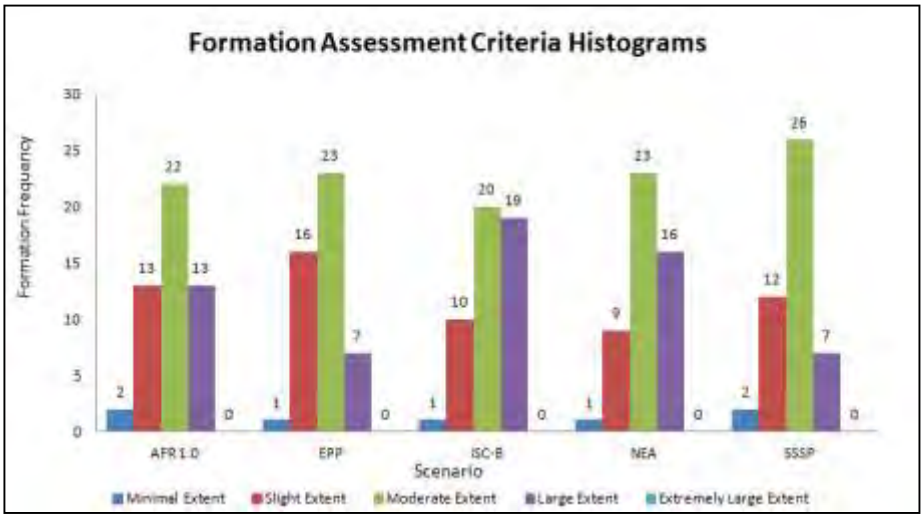


Figure 15. Distribution of Formation Extent of Contribution measure Means by Scenario

Inspection of the criteria and definition (see Figure 7) reveals that it was not possible to assess any alternative (formation) in that criterion simply because no one formation performs all tasks or functions required in any one of the scenarios. A minor correction to the definition for the criteria that provides the next increment above large extent could possibly resolve this error and should be implemented in the next iteration of CNA. A one-way ANOVA of the formation means in each scenario revealed differences in each of the 5 scenarios ($p<.05$). Figure 16, contains the result of a Tukey method test of means in each of the 5 scenarios to determine where there were significant differences between formation means in each scenario with 90% simultaneous confidence interval.

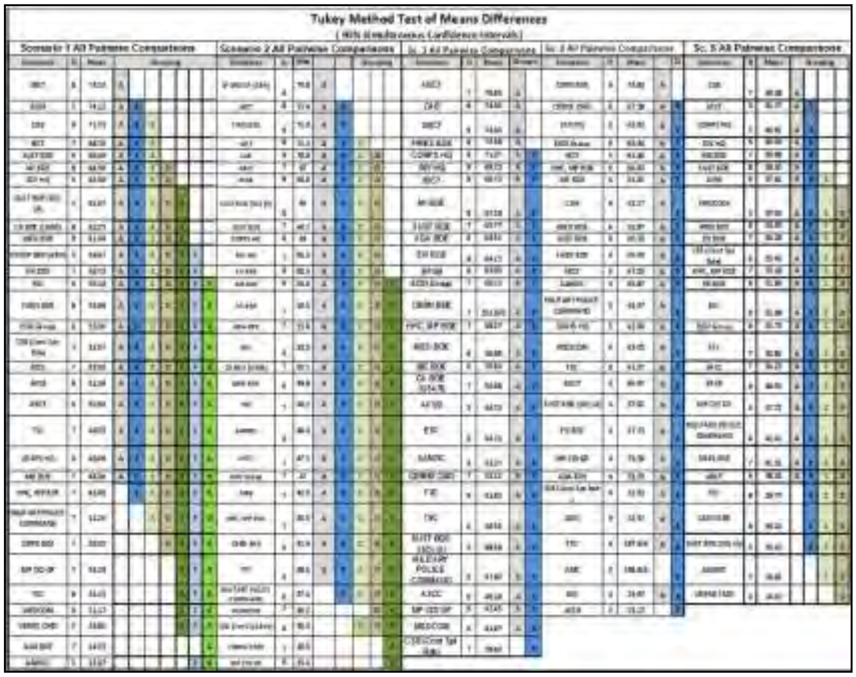


Figure 16. Results of Tukey Method Test of Formation Measure Sample Means

Groupings are shown by common letter associations and similar color cells. The Tukey method test showed that there are statistically significant differences in the means of the formations in each scenario. The preference of formations (as well as sets of formations where means are not different) that best contribute to mission accomplishment in each scenario vary. Also, by inspection of Figure 15, there are large groupings where the means are the same for multiple formation alternatives. This result was anticipated from post sample interviews of assessors that revealed most assessors felt that groups of formations were equally critical for conducting operations in the scenario. In fact, most operations, including the scenarios presented in the analysis, are sourced with multiple formations performing different functions, which as a whole, represent the capability needed to achieve mission accomplishment across the all 6 phases of an operation. Recall that the measure was designed to capture the value of the formation's function in the scenario without distinction of the phase of operations. Thus, it was possible for an assessor to equally value a formation that primarily performed

its function in phase II of operations with one that primarily performed its function in phase III. This distinction was not made during the survey, thus assessors made assumptions about a formations contribution based upon knowledge of operational phases that weren't being measured, leading to equalities among large groups of formations in the scenarios. Thus, providing clarity on formation value by phase of operation in comparison to one another would likely enable greater distinction among formations. Additionally, providing another meaningful criterion upon which to make distinctions between formation contributions to scenario objective achievement would improve this attributes contribution to alternative preference. Despite this weakness in distinguishing among individual formation contribution to scenario mission accomplishment, and the addition of another attribute criterion, the attribute's contribution to alternative preference is sufficient to engender confidence in the value model to produce correct results.

Task Contribution to Formation Mission Accomplishment Attribute.

The Task attribute was the first attribute in the value model not derived from sampling of experts but by eliciting value from a consolidated judgment of the proponent (experts and leaders) responsible for the task performance in the Army. Hence, the attribute's and measures' relevance was assessed only by analysis of the distribution of alternative among the measure criteria. (No evaluation of significant differences between means is possible since the consensus was achieved within a meeting of experts at the proponent). Inspection of Figure 17 generally reveals a distribution of Task alternatives across the measure criterion that enables distinction of formation contribution where few formations where highly valued, most formations were moderately valued and few formations were not valued. The alternative assessments on the constructed scales achieved an average across scenarios of 98 and 97.5% of the possible scale respectively for degree of formations mission accomplishment and impact on scenario Force's mission. One trend was noted. The exception to the expected distribution across criterion is

shown in Figure 17 in both measures of a task's contribution to formation mission accomplishment in the two scenarios where the task apportionment was skewed to the top two criteria. An explanation for this came from post-survey interviews with the proponents who nearly consistently stated that the

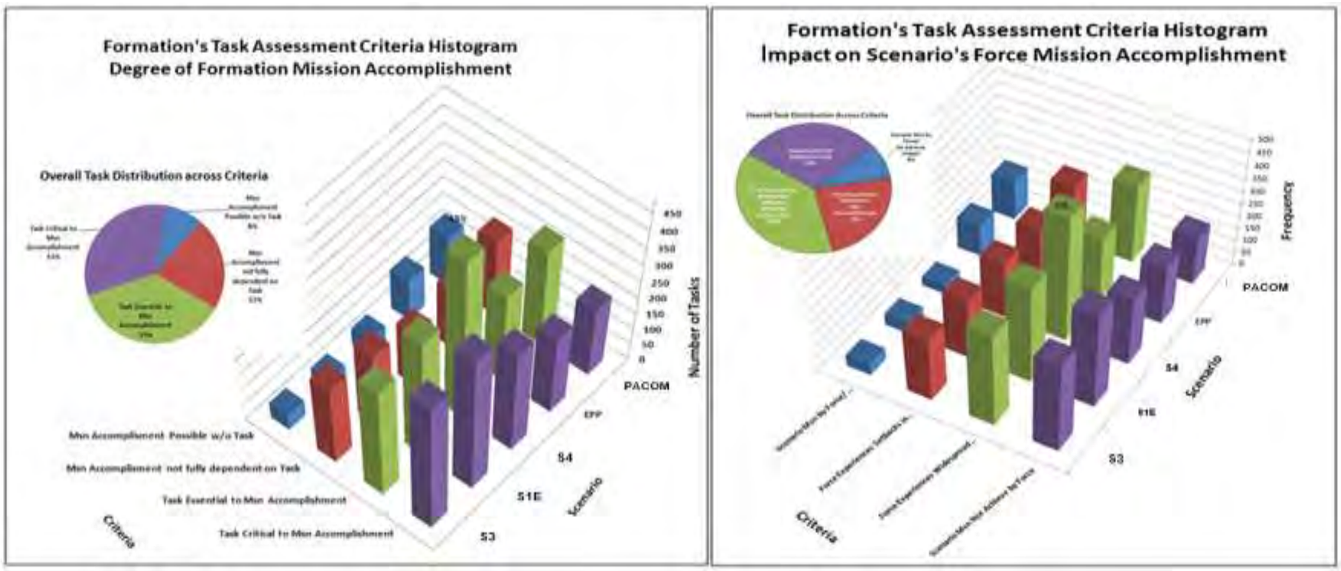


Figure 17. Distribution of Task Alternative across Measure Criterion

increased risk and urgency associated with combat operations of those scenarios caused a corresponding increase in the tasks value performed by formations. Simply, it was felt that more tasks were critical in S1E and S3 scenarios. As shown in Figure 18, a comparison of

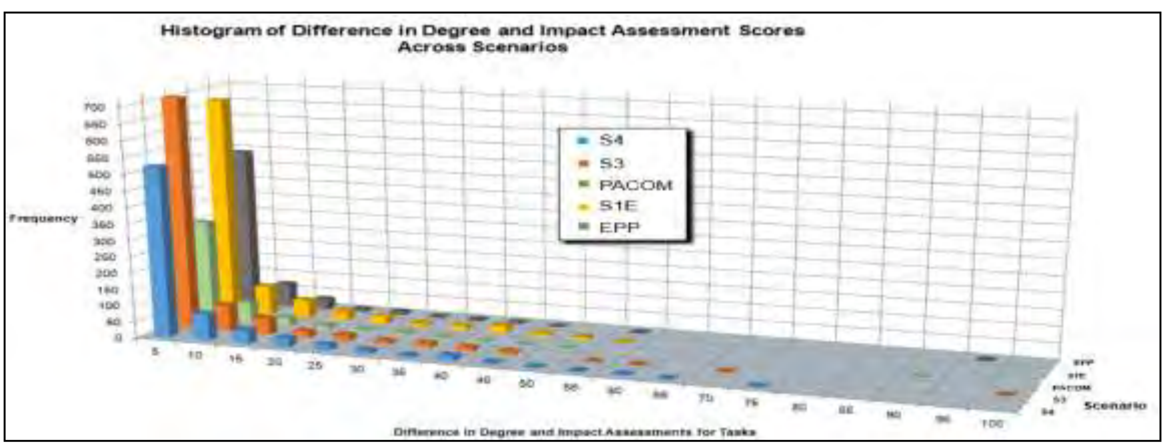


Figure 18. Magnitude of Difference in Two Task Criteria

the two criteria, degree of formations mission accomplishment and impact on scenario Force's mission, to one another in each of the scenarios shows that there was little difference in the assessment scores

between them. The distributions of difference in scores between the two criteria are left skewed to a small difference with the mean of the difference in scores ranging from 4.4 to 6.4. Thus, though the use of the levels of each criterion is effective in determining preference both criteria are nearly identical across the levels for each task in each scenario suggesting that both criteria are not necessary. Investigating the change in solution value or order by eliminating one of the two criteria suggests, as shown in Figure 19, that eliminating either criteria has little effect on the solution values or solution order.

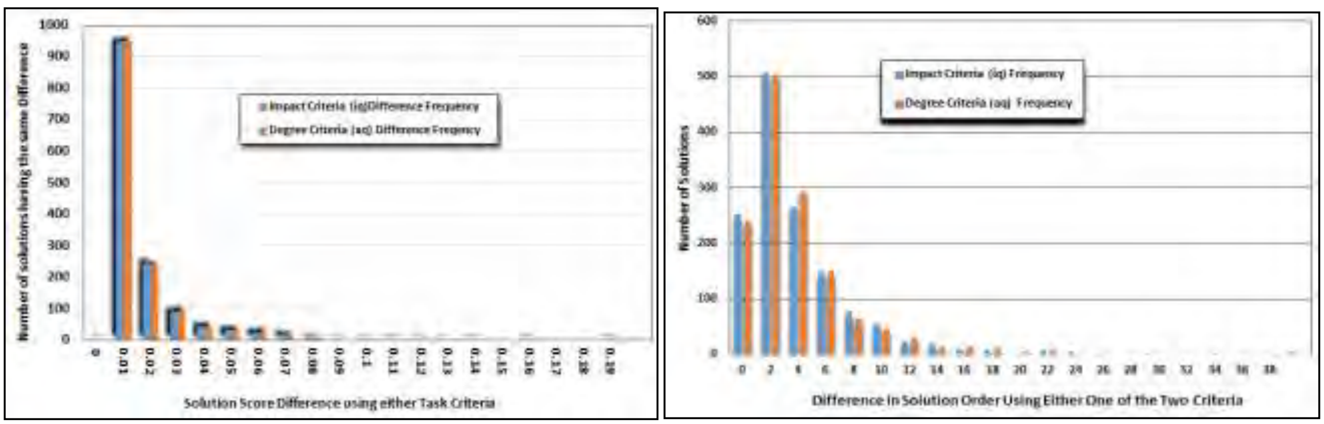


Figure 19. Comparison of Task Assessment Criteria Selection on Solution Order and Score

DOTMLPF Fielded or Programmed Solutions Achievement of the Task Attribute

The achievement of the task attribute, as pointed out earlier, was measured on a constructed scale of extent of achievement of the task with 5 possible levels to return a value for each solution. Inspection of Figure 20 shows that solutions were distributed across the 99% of the scale (1-100). However, for most Formations or Warfighting Functions, the distribution of DOTMLPF solutions is skewed toward the lower end of the scale indicating most solutions have smaller contribution to achieving the tasks. Overall, 57% of the solutions were scored in the lower two criteria (minimal and slight) with only 17% in the upper two criteria (large and extremely large extent of achievement). This was expected since most tasks require multiple solutions each contributing some ability to reach full achievement under the

conditions (across scenarios) to the listed condition or standards. Thus, in general, the measure was adequate and relevant in assisting in distinguishing between alternatives' ability to achieve the task.

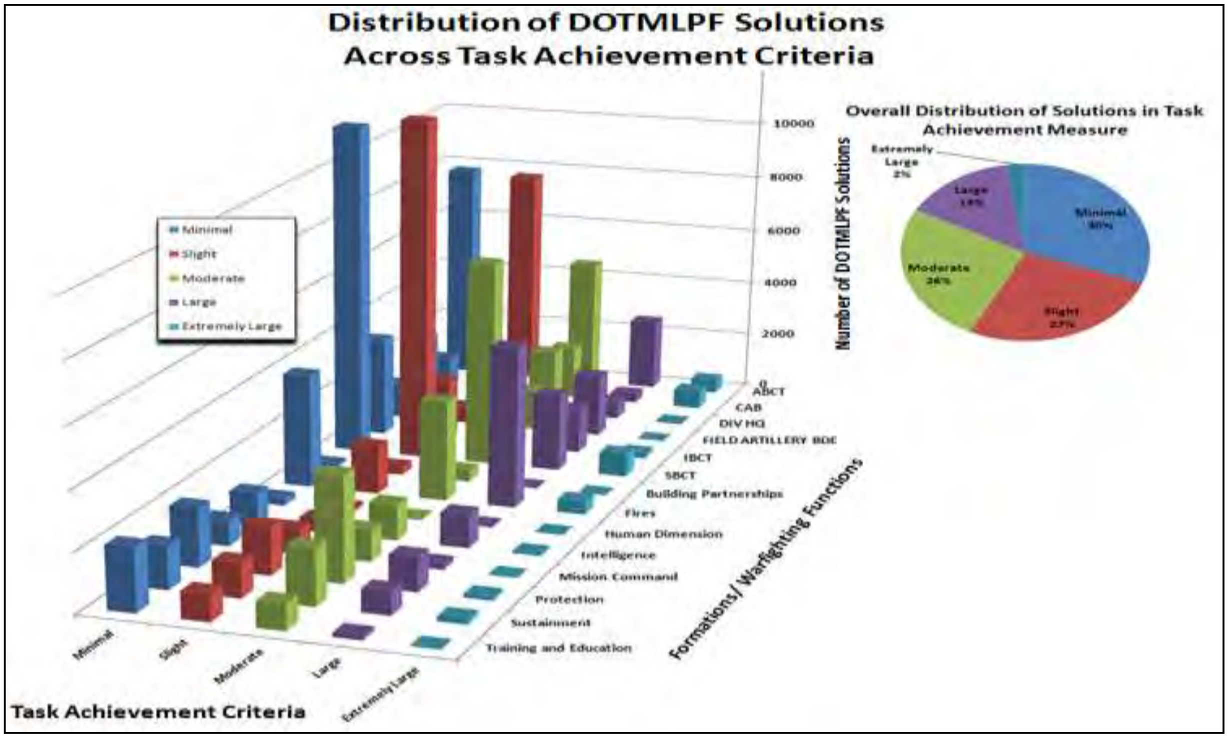


Figure 20. Distribution of DOTMLPF Solutions across Task Achievement Criteria

Capability Gap Operational Risk Attributes

Recall that the Capability Gap Operational Risk attribute consists of two measures, likelihood that the gap will occur and consequence on force mission accomplishment in the scenario when the gap occurs. Examination of Figure 21 shows that Gap alternatives were assessed across 99% of the 1-100 in each measure. For likelihood of occurrence measure the gap alternatives were concentrated in the Likely (42%) and Occasional (47%) criteria. For consequence measure the gaps were concentrated in the critical (45%) and marginal criteria (50%). Both of these results are easily explainable given that there are few tasks for which the Army cannot develop a work-around using doctrine or rapid changes to force structure.

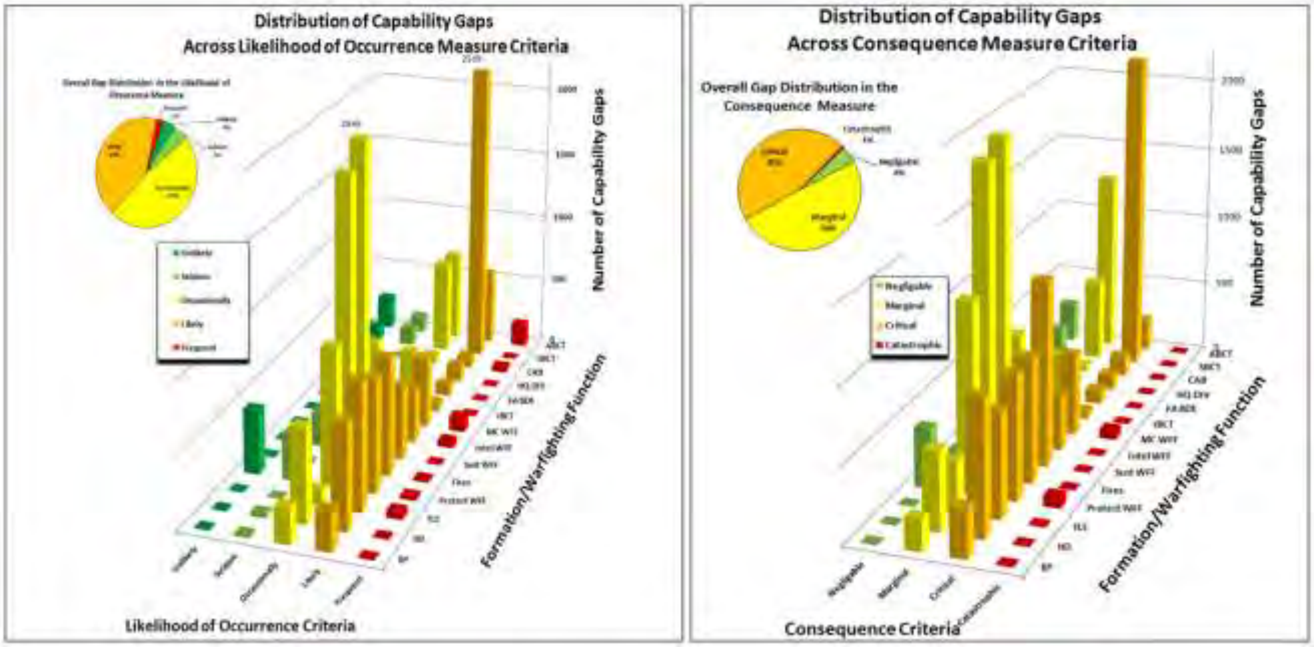


Figure 21. Distribution of Capability Gaps across Risk Criteria

Thus, the both measures for the Gap risk attribute were relevant in distinguishing preference among the identified capability gaps.

Idea for Non-materiel or Materiel Solution Approach Extent of Gap Mitigation Attribute

The attribute associated with preference between Solution Approach/Idea is the extent the Solution/Idea contributes to mitigating a capability gap. As shown in Figure 22, the solutions/ideas were assessed across the attribute criteria with a preponderance of the solutions rated in the middle categories and a small number in the upper and lower criteria categories. This indicates that the criterion is adequate and sufficient to enable preference among the solutions/ideas.

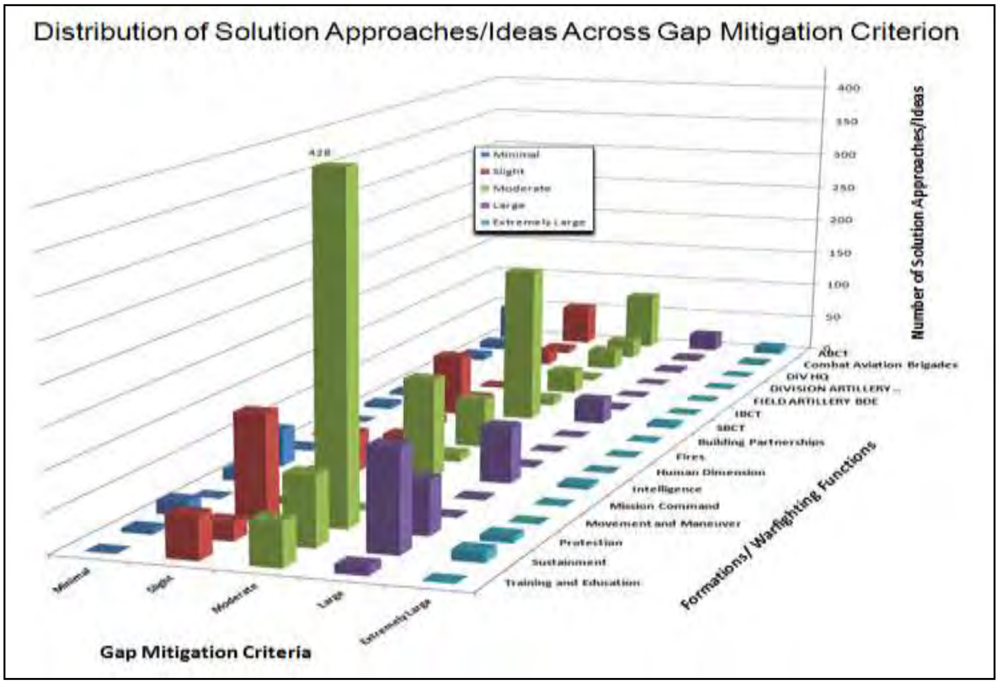


Figure 22. Distribution of Gap Solution Approaches/Ideas across Gap Mitigation Criteria

Alternative Preference Sensitivity to Changes in Attribute Weightings

Although the preceding analysis is necessary for understanding of the relevance of the measures contribution to preference, the more conventional sensitivity analysis of an additive value model is to examine the sensitivity of changes in alternative preference to changes in the weights of the attributes comprising the value hierarchy[15]. The simplest (least computationally intensive) and most common sensitivity analysis technique is the one-at-a-time analysis where one weight is varied from 0-1 while maintaining the others constant.[16] Evaluating the results of the changes in alternative preference is best conceptualized by graphing alternative preference compared to attribute weight change and noting, especially in the relevant measured range of the attribute, the extent of intersection of the lines

[15] Kirkwood, G.W. Strategic Decision Making; Multiobjective Decision Analysis with Spreadsheets, Wadsworth, 1997, p82.
[16] Hamby, D.M. 1994. A Review of Techniques for Parameter Sensitivity Analysis of Environmental Models. Environ. Monit. and Assess, *,p139.*

representing the alternatives. Intersecting lines (non-equal linear slopes) indicate preference change as the attribute changes weighted value. The more alternative lines intersect, the greater the preference for the alternative is sensitive to the attribute weight. Ideally, it is desired to have little or no sensitivity to change in attribute weights. Thus, it becomes important to closely examine an attribute for unintended effects (e.g., errors) where the alternative's preference is overly sensitive to changes in the attribute in order for decision makers to have confidence in the model's recommended preferences. Since each attribute had some irregularities identified in the attribute relevance analysis, we examine the alternatives preference sensitivity to each of the four swing weights (scenario risk to mission accomplishment, formation contribution to mission accomplishment, task contribution to formation mission accomplishment, and for gap solutions, the gap's risk to the Army) that are part of the 3 additive value models using the one-at-a-time analysis and the Sensitivity Index (SI)[17] of the alternatives for each attribute. We also, then where appropriate use statistical techniques to gain further understanding of the one-at-a-time analysis and SI results.

Sensitivity of DOTMLPF-P Solutions to Sustain in the POM Preference to Scenario Weight

Figures 23 show the sensitivity of the preferential order of DOTMLPF solutions given a change in scenario weights. Since there are more than 1400 solutions alternatives we examine alternatives at the top of the order (where programs must be sustained in the POM to avoid high risk), and where decision makers arbitrarily chose to delineate between groups of solutions (i.e., Tier I and Tier II, and, Tier II and Tier III). Inspection of the Figure 23 shows that the preference for the top 20 solutions are insensitive to changes in scenario weights in the relevant range (of the 20 examined only two, solution

[17] Hamby, D.M. 1994. A Review of Techniques for Parameter Sensitivity Analysis of Environmental Models. Environ. Monit. and Assess, p140.

19 and 17 trade a single order). Thus, we have high confidence in the value model distinguishing preference in the top solutions using the scenario attribute.

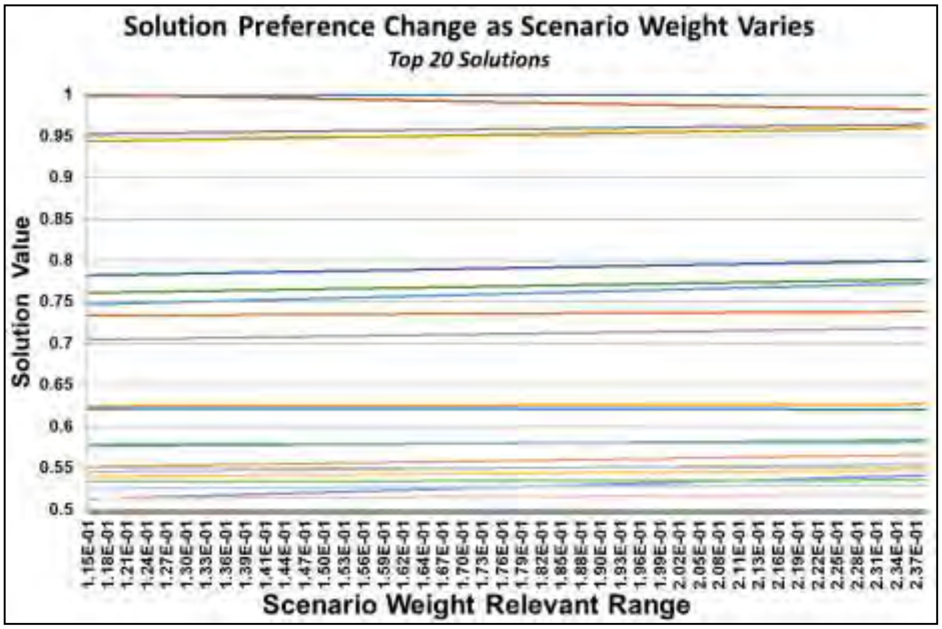


Figure 23. Top 20 DOTMLPF Solution Preference Sensitivity to Scenario Weight Variation

Examination of Figure 24 shows significant sensitivity of the solutions alternatives surrounding the Tier delineations indicating that with a change in scenario weight the solutions would easily change tier.

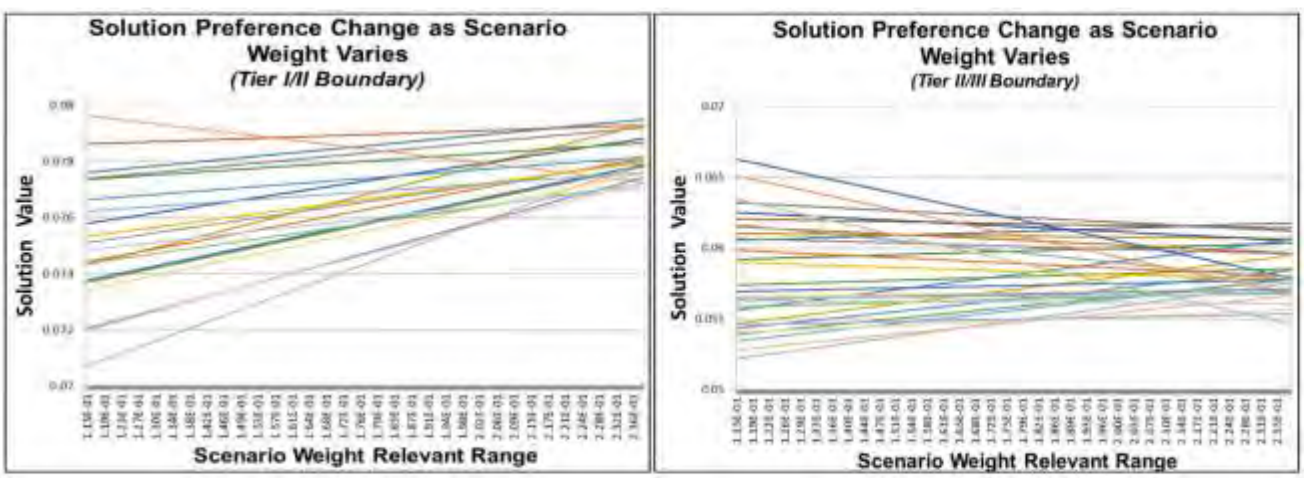


Figure 24. Solution Preference Sensitivity to Scenario Weight Variation at Decision Tier Interface

The Tier II/III boundary is of particular concern, as a great many of the solutions would change tiers with slight change in scenario weight. This result is at least partly due to the focused attention to assessments in tier I and decreasing attention to assessments outside of tier I observed during the elicitation process. Thus, solution value changes would result in solutions on both sides of these arbitrary interfaces switching tiers making the tier boundaries ineffective in distinguishing preferences, and thus not aide decision making. This suggests that for future assessments, to improve acceptability of the results, an analysis of the sensitivities of solution values to scenario weight changes could be used to set the tier boundaries by minimizing preference changes across potential boundaries in lieu of arbitrary establishment of those boundaries along quintiles.

DOTMLPF-P Solutions Attribute Preference Sensitivities due to Formation Weight Variation.

The sensitivity of solution preference to variation in weights used for the formations contribution to scenario mission achievement attribute in the mutli-attribute value model is shown in Figure 25. By inspection of Figure 25(a), solution preference for the top 20 solutions shows that there is some sensitivity to variation of the formation weights across the relevant range (elicited range of weights for each formation). Analysis of the change shows that the change in preference varies only a few positions at most across the range. Inspection of Figure 25 (b) and (C) shows the alternative sensitivity at the tier boundaries, tier I/II and tier II/III respectively. Again, the sensitivity was of greater concern at the tier boundaries since this implies that solutions in one tier would cross tier boundaries for changes across formation weight range. Thus, like the scenario attribute, except for at the tier boundary, the solution alternative preference sensitivity to formation weight change is minimal and acceptable to give confidence in the preference of the alternative.

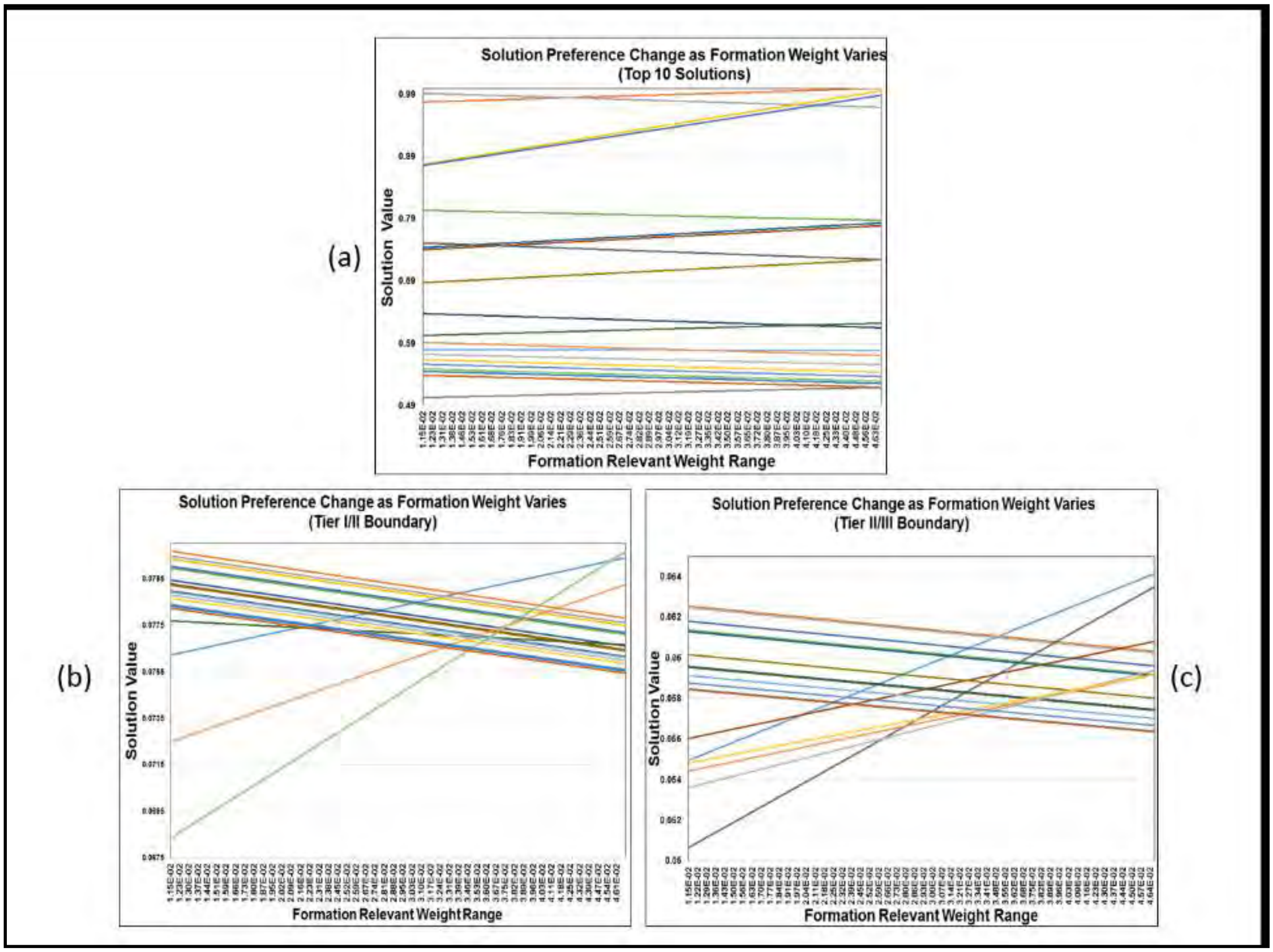


Figure 25. DOTMLPF Solution Preference Sensitivity to Formation Weight Variation

Although not ideal, this degree of sensitivity was deemed acceptable for the purposes of the CNA. However, taking action to improve the use of the formation criteria for the attribute and selecting the proper tier boundary using the one-at-a-time analysis is necessary to increase confidence in the tiering technique.

Solution Preference Sensitivities due to Task Weight Variation

The third set of attributes weighting used in solution preference is a Tasks weight. It consisted of 2 separate attributes that were multiplied together and normalized for the set of tasks in each formation in each scenario. Figure 26 shows the sensitivity of a solution's value given variation of task weight from 0-1 while maintaining the other weights proportionately constant. Figure 25(a) shows that that there is sensitivity to task weight change among the top 20 alternatives examined and (b) and (c) also show sensitivity to variation of task weight of solutions at the arbitrary tiering boundaries. In these three

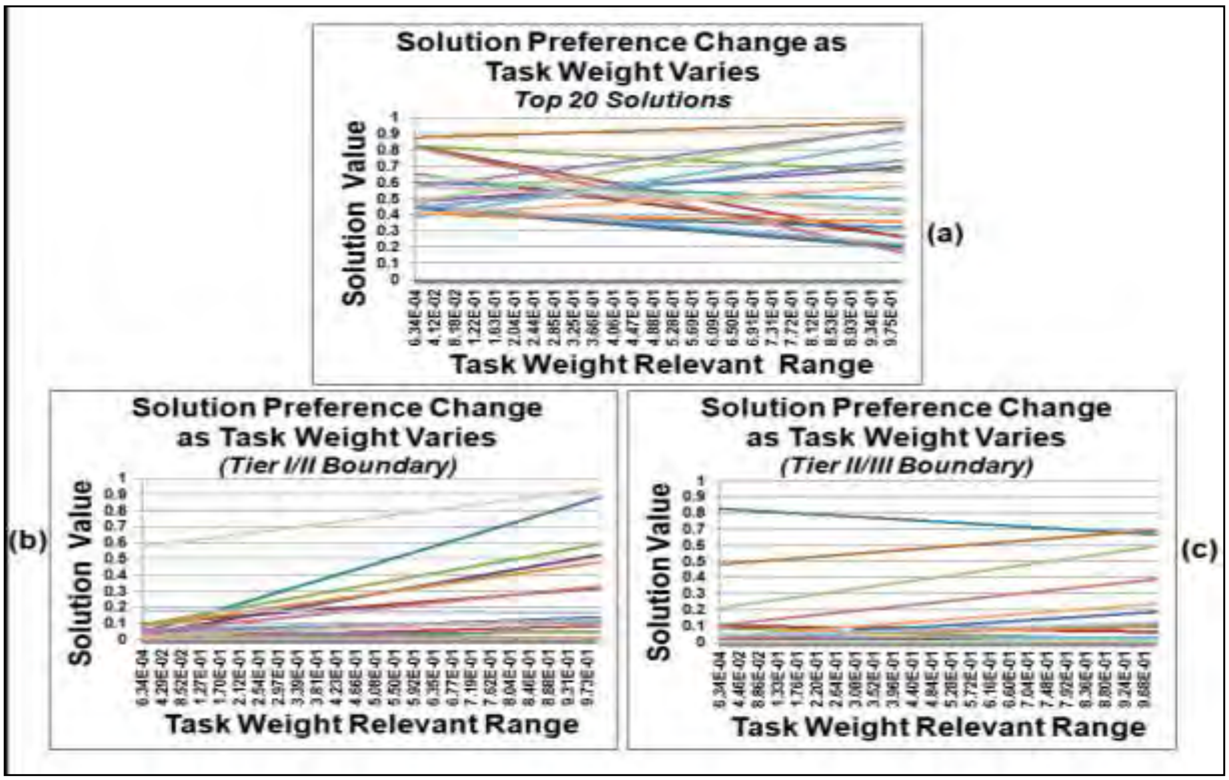


Figure 26. Solution Alternative Preference Sensitivity Due to Task Weight Variation

instances this sensitivity to tasks may reduce confidence in solution preference if it was the result of either type 1 or 2 errors in the constructed scale and criterion, or the elicitation process. Prior analysis of the two separate attribute criterion determined the assessors used the entire scale range; however, assessors treated both attributes for the task equally. Thus, a second criterion did not help in the

preference. Revision of the second criterion is required to help with preference. This may also help reduce the solution alternative sensitivity to the task.

Gap Alternative Preference Sensitivities due to Scenario, Formation and Task Weight Variation

Similar to the Solution alternative sensitivity analysis, Figure 27 illustrates that the top 20 (tier I) capability gap alternatives were not sensitive to scenario (a) and formation (b) attribute weights, but were sensitive to task (c) attribute weights. Also, similar results to the solution alternative analysis at the tier boundaries was observed in the data for capability gaps between tier I and II and II and III.

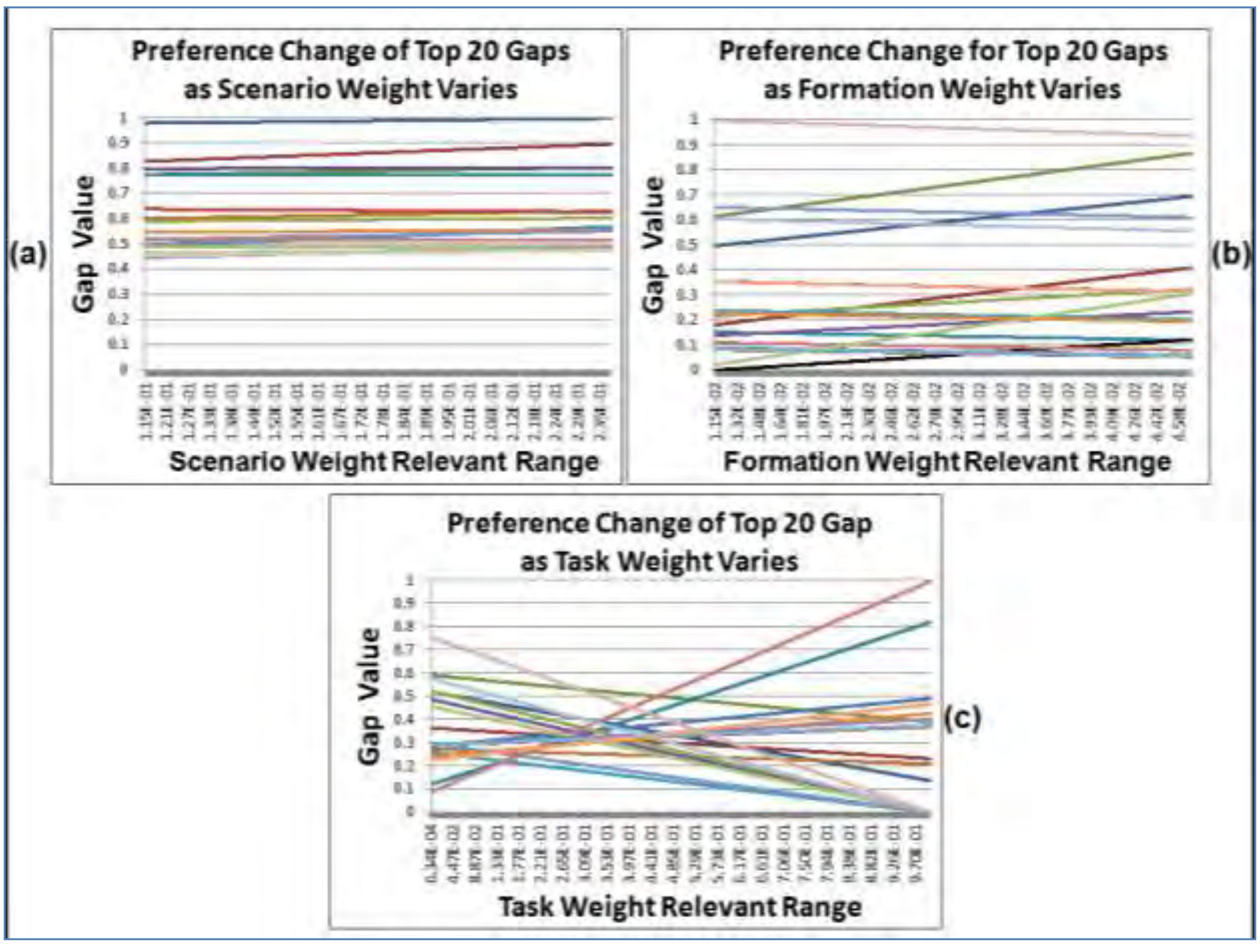


Figure 27. Gap Preference Sensitivity One-to-one Analysis (Top 20 Gaps)

Gap Idea for Non-Material and Materiel Solution Approach Preference Sensitivities due to Attribute Weight

Similar to the Solution and Gap alternatives sensitivity analysis, Figure 28 illustrates that the top Ideas for Non-Materiel and Ideas for Materiel Approaches (subsequently referred to as Ideas) alternatives were not sensitive to scenario and formation attribute weights, but were sensitive to task attribute weights.

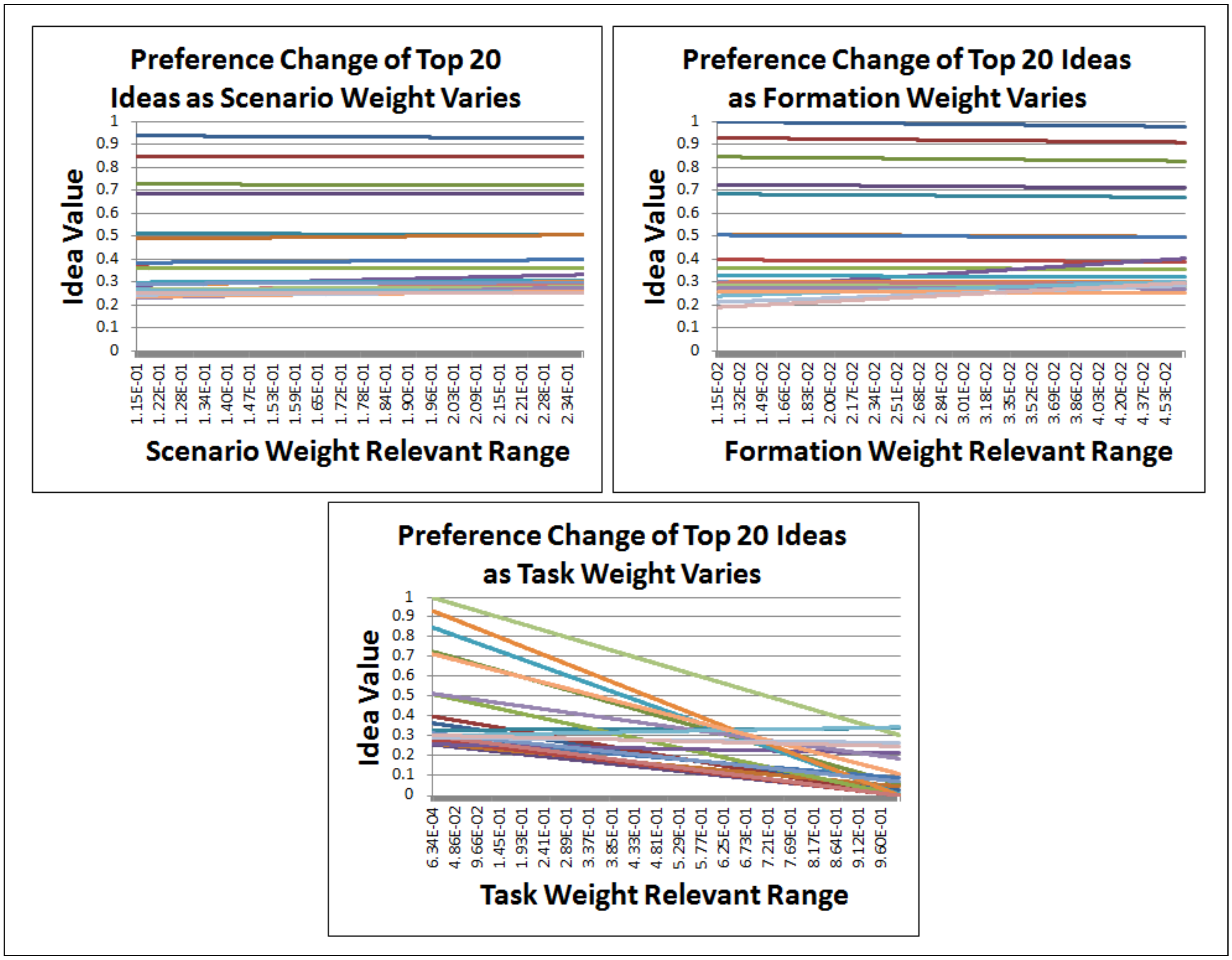


Figure 28. INMA/IMA Preference Sensitivity One-to-one Analysis (Top 20 Ideas)

Confirming the One-to-One Sensitivity Analysis

Hamby suggests[18] that a quantitative measure of alternative's preference sensitivity to attributes weights can be measured effectively by a Sensitivity index. The index (SI) is given by:

$$\boldsymbol{SI = \frac{Dmax - Dmin}{Dmax}}$$

Where the ***Dmax*** is the maximum value for the alternative when the attribute weight is at maximum variation and ***Dmin*** is the minimum value of the alternative when the attribute weight is at minimum variation. Solutions with indices close to 1 are sensitive and those with indices near 0 are insensitive to the attribute weight. Applying the Sensitivity Index to the CNA solution attribute across more than 1400 solution alternatives resulted in histograms of number of solutions in each SI bin as shown in Figure 29. Inspection of the figure shows a distribution of solution alternative SI near zero for the scenario and formation attribute weights, while the distribution of solution alternative SI for task attribute weights is spread across the indices scale with a concentration near 1. This data supports the one-to-one-analysis of the solution alternative sensitivity. For the scenario and formation attribute weights, the solution preference is relatively insensitive compared to the task attribute weight. As with the one-to-one analysis the solution preference is sensitive to the variation in task weight.

[18] Hamby, D.M. 1994. A Review of Techniques for Parameter Sensitivity Analysis of Environmental Models. Environ. Monit. and Assess., p140.

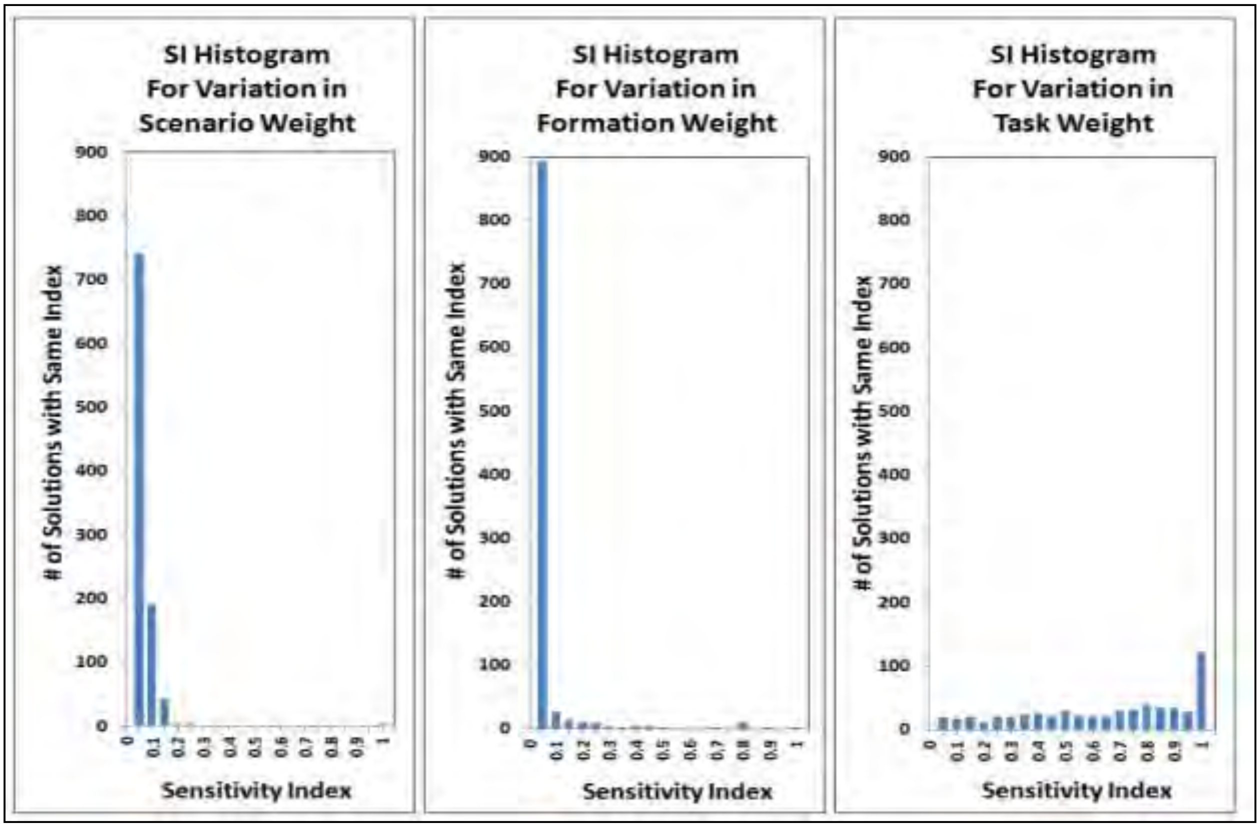


Figure 29. Histograms of Solution Attribute Sensitivity Index

Other Observed Relationships between Alternatives and Attributes

To better understand the sensitivity of the alternative's preference to the attribute weight, we examined the relationship between the two variables (attribute weight and alternative preference) using statistical correlation tests. Since a test of normality and linearity showed the data associated with attribute and alternatives was not linear, non-normal, but monotonic, the Spearman Rank Coefficient was chosen to analyze the variable's relationship. The Spearman's Rank Correlation coefficient (ρ) is highlighted as one of the more straight forward non-parametric methods to use in additive value model sensitivity analysis[19]. Specifically, the correlation between the rank of the alternatives and the paired rank of the

[19] Hamby, D.M. 1994. A Review of Techniques for Parameter Sensitivity Analysis of Environmental Models. Environ. Monit. and Assess., p140,

number formations or tasks associated with the alternatives. After transforming the number of formations and tasks paired to each attribute (solution or gap) to ranks across the Spearman Rank Coefficient for was computed. Table 2 shows the correlation between ranks of the alternative (across the row) and ranks of the attribute (down the column). Thus, there is no significant correlation between the formation and solution ranks or between the solution and task number ranks.

Paired Alternatives Rank Compared		**Spearman's Rank Coefficient (ρ)**		
		Set of All Alternatives	**Set of M Alternatives Only**	**Set of M Programmed Alternatives Only**
Solution Alternatives	**Formation Rank** (based on number of formations where solution existed)	**.380**	**TBP**	**.361**
	Task Rank (based on number of tasks solution helped achieve)	**.647**	**.734**	**.754**
INMA/IMA Alternatives	**Formation Rank** (based on number of formations where INMA/IMA existed)	**0.018**	**.056**	**NA**
	Task Rank (based on number of tasks INMA/IMA helped achieve)	**0.623**	**.659**	**NA**
Gap Alternatives	**Formation Rank** (based on number of formations where gaps existed)	**0.615**	**NA**	**NA**
	Task Rank (based on number of tasks gaps helped achieve)	**0.466**	**NA**	**NA**

Table 2. Spearman's Rank Coefficient for Paired Alternative Rank and Attribute Rank

Summary and Recommendations for Continued Refinement

Compensatory Additive Value modeling, a widely accepted Decision Analysis technique, was applied to assist in resource decisions on numerous alternatives across multiple conflicting objectives. The scope of the application involved three separate but related value models to determine preference on more than 1400 DOTMLPF-P solution alternatives, 800 Capability Gap alternatives, and 300 gap solution alternatives. This scope made implementation complex, requiring extensive resources (manpower effort, and technical solutions), and collaboration among more than 20 stakeholder agencies. An automated information system was developed to collect, assess and analyze data which enable the complex collaboration required to achieve success. None the less, those complexities clearly introduced some error in the results. However, the results were widely accepted as the best analytically robust available to enable resource decision making by the community and stands as the command position for use by all. Detailed analysis of the model elements compared with the intended purpose of the element revealed areas where refinement could improve confidence in the results. Analysis of the use of the attribute scales and criteria showed most of these model elements were effective in contributing to preference. However, the scenario attribute likelihood criteria, and formation criteria should be refined to allow for measurement across the entire attribute's scale for better preference determination. Sensitivity analysis of attribute weights for the each of the 3 value models showed preference was not significantly sensitive to 3 of four attributes used. The preference for alternatives in each of the three values models was sensitive to the weights of the attribute associated with the contribution of tasks to mission accomplishment and requires refinement to improve preference confidence. This improvement includes eliminating one of the two criteria since the data showed that assessors did not or could not distinguish between the criteria. Adding a distinct criteria may aid in preference determination and reduce the strong sensitivity to this attribute that was observed. Additionally, a linkage between model 1 and 3 to enable comparison of the values of programs and emerging idea's that could become

programs is desired by many of the stakeholders. This would be relatively straight forward since both models share the same elements in the value model. A simple method to relate their value to task for programs and the value to gap solution would be required. This would logically be possible as a gap is the unachieved portion of a task (or multiple tasks).

Technical References

Bott, J.M., Gross, A.A., Burk, R.C., Parnell, G.S., CAA Peer Review of ARCICs CNA Process, White Paper, Feb 2014.

Edwards, W., Barron, F.H., SMARTS and SMARTER: Improved Simple Methods for Multiattribute Utility Measurement, 1994, Organizational Behavior and Human Decision Processes, 60, pp. 306-325.

Ewing, L., Dell, R.F., MacCalman, M., Whitney, L., Capability Portfolio Analysis Tool (CPAT) Verification and Validation Report. Defense Technical Information Center, NPS-OR-13-001, Naval Postgraduate School, Monterey California, January 2013.

Hamby, D.M. 1994. A Review of Techniques for Parameter Sensitivity Analysis of Environmental Models. Environ. Monit. and Assess.p.139-140.

Keeny, R.L., Value-Focused Thinking: A Path to Creative Decisionmaking, Harvard University Press, Cambridge, Massachusetts, 1992, p. 82. pp.104-117.

Keeny, R.L., Raiffa, H., Decision With Multiple Objectives, Cambridge University Press, 1993.

Kirkwood, G.W. Strategic Decision Making; Multiobjective Decision Analysis with Spreadsheets, Wadsworth, 1997, p82

Krondak, et. al., TRADOC Scenario Gist Book, TRAC-F-TR-13-016, ATTN: ATRC-FD, TRADOC Analysis Center, 255 Sedgwick Ave., Fort Leavenworth, KS 66027-2345

Linstone, H. A. and Turoff, M. (eds., 1975): The Delphi Method - Techniques and Applications, Reading: Addison-Wesley, 2002.

Parnell, G.S., Driscoll, P.J., and Henderson, D.L., Editors**,** Decision Making for Systems Engineering and Management, 2nd Editions, Wiley Series in Systems Engineering, Wiley & Sons Inc. , 2011.

Abbreviations

Acronym	Expansion
AAR	After-action Report
ACF	Army Concept Framework
ACoE	Aviation Center of Excellence
ACSIM	Assistant Chief of Staff for Installation Management
AEWE	Army Expeditionary Warrior Experiment
AMC	Army Materiel Command
AMEDD	Army Medical Department
AOC	Army Operating Concept
ArCAT	Army Capabilities Analysis Tool
ARCIC	Army Capabilities Integration Center
ARSTAF	Army Staff
ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics and Technology
ASCC	Army Service Component Command
AWFC	Army Warfighting Challenges
AWG	Asymmetric Warfare Group
AUTL	Army Universal Task List
BDE	Brigade
BL	Battle Lab
BLCSE	Battle Lab Collaborate Simulation Environment
CAB	Combat Aviation Brigade
CAC	Combined Arms Command
CARD	Capabilities and RAM Division
CASCOM	Combined Arms Support Command
CBA	Capabilities-based Assessment

Acronym	Expansion
CCoE	Cyber Center of Excellence
CDD	Capabilities Development Directorate
CDID	Capability Development Integration Directorate
CG	Commanding General
CNA	Capabilities Needs Analysis
CoC	Council of Colonels
CoE	Center of Excellence
CoL	Campaign of Learning
COIN	Counterinsurgency
CPR	Capability Portfolio Review
CSA	Combat Support Agency
CWMD	Counter Weapons of Mass Destruction
Cyber STE	Cyber Set the Experiment
DoD	Department of Defense
DOTD	Directorate of Training Development and Doctrine
DOTMLPF-P	Doctrine, Organization, Training, Materiel, Leadership, Personnel, Facilities and Policy solutions
DP	Decision Point
DPG	Defense Planning Guidance
DTG	Date-Time-Group
EAD	Echelons Above Division
EEA	essential elements of analysis
EPP	Enhanced Protective Posture
FAA	Functional Area Analysis

Acronym	Expansion
FCoE	Fires Center of Excellence
FM	Force Modernization
FNA	Functional Needs Analysis
FORSCOM	U.S. Army Forces Command
FSA	Functional Solutions Analysis
FY	Fiscal Year
GAMEX	Wargame/Exercise
GOSC	General Officer Steering Committee
HQ TRADOC	Headquarters, U.S. Army Training and Doctrine Command
HQDA	Headquarters, Department of Army
IAW	In accordance with
I/A/SBCT	Infantry/Armor/Stryker Brigade Combat Team
ICW	In Coordination With
ICDT	Integrated Capabilities Development Team
ICoE	Intelligence Center of Excellence
ICW	In-coordination with
IICDT	Intelligence Integrated Capabilities Development Team
IMA	Ideas for Material Approaches
INMA	Ideas for Non-material Approaches
JAG	Judge Advocate General
JCIDS	Joint Capabilities and Integration Development System
JIEDDO	Joint Improvised Explosive Device Defeat Organization
JTC	Joint Training Center
IMA	Idea for Materiel Approach

Acronym	Expansion
INMA	Idea for Non-Materiel Approach
ISR	Intelligence, Surveillance, Reconnaissance
IWfF	Intelligence Warfighting Function
LIRA	Long-range Investment Requirement Analysis
MSEL	Mission Essential Task List
MCCoE	Mission Command Center of Excellence
MCoE	Maneuver Center of Excellence
MSCoE	Maneuver Support Center of Excellence
MSO	Major Subordinate Organization
NIE	Network Integration Evaluation
NLT	No later than
PACOM	Pacific Command
PBR	Program Budget Review
PED	Processing, Exploitation, & Dissemination
PEG	Program Evaluation Group
PIR	Priority Intelligence / Information Request
PMJ	Professional Military Judgment
POC	Point of Contact
POM	Program Objective Memorandum
PPBE	Planning, Programming, Budgeting and Execution
RC	Required Capability
REF	Rapid Equipping Force
RSVP	Request for Response
S&T	Science and Technology

Acronym	Expansion
SCoE	Sustainment Center of Excellence
SIMEX	Simulation/Exercise
SMDC	Space and Missile Defense Command
SSA	Support to Strategic Analysis
SSI	Soldier Support Institute
STE WG	Set the Environment Working Group
SWG	Seminar Wargame
SME	Subject Matter Expertise/Subject Matter Expert
SWG	Seminar War Game
T/C/S	Tasks, Conditions, & Standards
TOE	Table of Organization and Equipment
TRAC	TRADOC Analysis Center
TRADOC	U.S. Army Training and Doctrine Command
TRISA	TRADOC Intelligence Support Activity
TWV	Tactical Wheeled Vehicle
UC	Unified Challenge
UJLT	Universal Joint Task List
ULO	Unified Land Operations
UQ	Unified Quest
USASOC	U.S. Army Special Operations Command
WfF	Warfighting Function

Glossary

<u>Capability</u>—The ability to complete a task or execute a course of action under specified conditions and level of performance.

<u>Capability developer (CAPDEV) --</u>A person who is involved in analyzing, determining, prioritizing, and documenting requirements for doctrine, organizations, training, leader development and education, materiel and materiel-centric DOTMLPF requirements, personnel, facilities and policy implications within the context of the force development process. Also responsible for representing the end user during the full development and lifecycle process and ensures all enabling capabilities are known, affordable, budgeted, and aligned for synchronous fielding and support.

<u>Capability Gap</u>—The inability to meet or exceed a capability requirement, resulting in an associated operational risk until closed or mitigated. The gap may be the result of no fielded capability, lack of proficiency or sufficiency in a fielded capability solution, or the need to replace a fielded capability solution to prevent a future gap.

<u>Capability Need</u>—See "Capability Requirement."

Capability Requirement—A capability required to meet an organization's roles, functions, and missions in current or future operations. To the greatest extent possible, capability requirements are described in relation to tasks, standards, and conditions in accordance with the Universal Joint Task List or equivalent DoD Component Task List. If a capability requirement is not satisfied by a capability solution, then there is also an associated capability gap. A requirement is considered to be "draft" or "proposed" until validated by the appropriate authority.

<u>Capability Requirement Document</u>—any document used to articulate either deliberate or urgent/emergent capability requirements and associated information pertinent to review and validation.

Capability Solution—A materiel solution or non-materiel solution to satisfy one or more capability requirements and reduce or eliminate one or more capability gaps.

Capstone concept --A capstone concept is a holistic future concept that is a primary reference for all other concept development. This overarching concept provides direct linkages to national and defense level planning documents. A capstone concept drives the development of subordinate concepts. For example, the CCJO drives development of joint concepts and service concepts. TP 525-3-0 drives the development of the Army operating and functional concepts.

Contingency Operation—A military operation that (a) is designated by the Secretary of Defense as an operation in which members of the Armed Forces are or may become involved in military actions, operations, or hostilities against an enemy of the United States or against an opposing military force; or(b) Results in the call or order to, or retention on, active duty of members of the Uniformed Services under section 688, 12301(a), 12302, 12304, 12304a, 12305, or 12406 of [title 10], chapter 15 of [title 10], section 712 of title 14, or any other provision of law during a war or during a national emergency declared by the President or Congress. (Source: 10 U.S.C. 101.)

Community of practice (CoP)--This is a group of organizations with a common interest in a subject area who interact to share information, processes, and products. A CoP is defined by three characteristics: the shared domain of interest, the relationships defining the community (typically networked, consisting of the organizations as nodes), and a shared set of practices for the subject area.

Concept-- A notion or statement of an idea – an expression of how something might be done – that can lead to an accepted procedure (CJCSI 3010.02C). A military concept is the description of methods (ways) for employing specific military attributes and capabilities (means) in the achievement of stated objectives (ends). An Army concept describes a problem or series of problems to be solved, assumptions, the future operational environment, the central idea, the components of the solution, the interaction of those components in solving the problem, and the required capabilities necessary to achieve desired effects and objectives.

Concept of operations (CONOPS) --A verbal or graphic statement, in broad outline, of a commander's assumptions or intent regarding an operation or series of operations (CJCSI 3170.01H). A concepts-based CONOPS is a statement, in broad outline, of a commander's assumptions or intent about an operation or series of operations. It is designed to give an overall picture and a useful visualization of how a future operation would be conducted (TP 71-20-3).

Constraints, limitations, and assumptions (CLA)-- Constraints, limitations, and assumptions provide the framework for both the study team and the study sponsor to understand the conditions under which a study's results are applicable. Although commonly misrepresented or used interchangeably, these three terms are distinctly different in meaning and use in the context of a study. Constraints, limitations, and assumptions bound (scope) a study effort by identifying what must (or must not) and can (or cannot) be accomplished; frame the study space and set the stage for the study team's methodology development; serve as a "contract" between the study sponsor and the study team; and provide a basis for the sponsor to reconcile the study results with how the study was done.

Core Mission Area—DoD core mission areas identified under the most recent Quadrennial Roles and Missions review are: Homeland Defense and Civil Support (HD/CS); Deterrence Operations; Major Combat Operations (MCOs); Irregular Warfare; Military Support to Stabilization Security, Transition, and Reconstruction Operations; and Military Contribution to Cooperative Security.

(Source: 2009 Quadrennial Roles and Missions Review Report.)

Data -- A representation of facts, concepts, or instructions in a formalized manner suitable for communication, interpretation, or processing by humans or by automatic means (as it pertains to modeling and simulation).

Delphi Method -- a widely used and accepted method for gathering data from respondents within their domain of expertise. The technique is designed as a group communication process which aims to achieve a convergence of opinion on a specific real-world issue.

Document Sponsor—The organization submitting a capability requirement document. Solution sponsors for successor documents—Capability Development Documents (CDDs), Capability Production Documents (CPDs), and Joint DOTMLPF-P Change Recommendations (Joint DCRs)—may be different than the Requirement Sponsors for initial documents—Initial Capabilities Documents (ICDs), urgent operational needs (UONs), joint UONs (JUONs), and joint emergent operational needs (JEONs). Different Sponsors for requirements and solutions can occur when the initial document Sponsor does not have acquisition authority and a different organization is designated to develop and field a capability solution, or when one Sponsor elects to leverage a previously validated document generated by a different Sponsor.

DoD Components—OSD, the Military Departments, the Chairman of the Joint Chiefs of Staff, the CCMDs, the Office of the Inspector General of the Department of Defense, the Department of Defense Agencies, field activities, and all other organizational entities in the Department of Defense.

Experimentation -- The exploration of innovative methods of operating, especially to assess their feasibility, evaluate their utility, or determine their limits to reduce risk in the current force (today's operations) and the future force (developments). Experimentation identifies and verifies acceptable solutions for required changes in DOTMLPF to achieve significant advances in current and future capabilities. Experiments aid in validating the feasibility of future requirements determination efforts. TRAC's Definitions for Analysts, TRAC-TD-05-010 dated May 2005 defines experimentation as: The use of an event or series of events designed to investigate concepts or prototypes.

Force modernization proponent-- The HQDA principal official, commander, commandant, director, or chief of the respective center, school, institution, or agency with primary duties and responsibilities relative to DOTMLPF and related requirements for a particular function (i.e. Combined Arms Center is a force modernization proponent, but not a Center of Excellence). See AR 5-22.

Functional area --A functional area is a broad scope of related joint warfighting skills and attributes that may span the range of military operations. Specific skill groupings that make up the functional areas are approved by the JROC. See CJCSI 3170.

Gap—See "Capability Gap."

Integrated Priority List—A list of a Combatant Commander's highest priority requirements, prioritized across Service and functional lines, defining shortfalls in key programs that, in the judgment of the Combatant Commander, adversely affect the capability of the Combatant Commander's forces to accomplish their assigned mission. Also called IPL.

Integrated capabilities development team (ICDT) --An integrated team of key stakeholders and SMEs from multiple disciplines chartered by Dir, ARCIC to initiate the JCIDS process through conduct of the CBA to identify capability gaps in a functional area, identify nonmateriel and/or materiel approaches to resolve or mitigate those gaps, and develop an ICD and/or a DCR or DICR, when directed.

Joint—Connotes activities, operations, organizations, etc., in which elements of two or more Military Departments participate. (JP 1-02. Source: JP 1.)

Joint Emergent Operational Need (JEON)—UONs that are identified by a CCMD, CJCS, or VCJCS as inherently joint and impacting an anticipated contingency operation.

Joint Military Requirement—A capability necessary to fulfill or prevent a gap in a core mission area of the Department of Defense. (Source: 10 U.S.C. 181.)

Joint Urgent Operational Need (JUON)—UONs that are identified by a CCMD, CJCS, or VCJCS as inherently joint and impacting an ongoing contingency operation.

Materiel (Capability Solution)—All items (including ships, tanks, self-propelled weapons, aircraft, etc., and related spares, repair parts, and support equipment, but excluding real property, installations, and utilities) necessary to equip, operate, maintain, and support military activities without distinction as

to its application for administrative or combat purposes. See also equipment; personal property. (JP 1-02. Source: JP 4-0.)

Need—See "Capability Requirement."

Non-Materiel (Capability Solution)—Changes to doctrine, organization, training, (previously fielded) materiel, leadership and education, personnel, facilities, and/or policy, implemented to satisfy one or more capability requirements (or needs) and reduce or eliminate one or more capability gaps, without the need to develop or purchase new materiel capability solutions. (Upon approval of this document, this term and definition are proposed for addition to JP 1-02.)

Rapid Acquisition—A streamlined and tightly integrated iterative approach, acting upon validated urgent or emergent capability requirements, to: conduct analysis and evaluate alternatives and identify preferred solutions; develop and approve acquisition documents; contract using all available statutory and regulatory authorities and waivers and deviations of such, appropriate to the situation; identify and minimize technical development, integration, and manufacturing risks; and rapidly produce and deliver required capabilities.

Requirement—See "Capability Requirement."

Requirement Sponsor—See "Document Sponsor."

Scenario--This is a graphic and narrative description of area, environment, means (political, economic, social, and military), and events of a future hypothetical conflict. Scenarios provide a framework for assessing the U.S. force capabilities under specified situations; identifying potential improvements to Army, joint, and other service DOTMLPF; and evaluating proposed concepts and changes to the Army. See TR 71-4.

Solution—See "Capability Solution."

Solution Sponsor—See "Document Sponsor."

Sponsor—See "Document Sponsor."

Threat—The sum of the potential strengths, capabilities, and strategic objectives of any adversary that can limit or negate mission accomplishment or reduce force, system, or equipment effectiveness. It does not include (a) natural or environmental factors affecting the ability or the system to function or support mission accomplishment; (b) mechanical or component failure affecting mission accomplishment unless caused by adversary action; or (c) program issues related to budgeting, restructuring, or cancellation of a program.

Urgent Operational Need (UON)—Capability requirements identified as impacting an ongoing or anticipated contingency operation. If left unfulfilled, UONs result in capability gaps potentially resulting in loss of life or critical mission failure. When validated by a single DoD Component, these are known as DoD Component UONs. DoD Components, in their own terminology, may use a different name for a UON.

Validation—The review and approval of capability requirement documents by a designated validation authority. The JROC is the ultimate validation authority for capability requirements unless otherwise delegated to a subordinate board or to a designated validation authority in a Service, CCMD, or other DoD Component.